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DEVELOPMENT OF A DYNAMIC MODEL TO EVALUATE THE EFFECT OF NATURAL RESOURCE POLICIES ON RECOVERY FOLLOWING NUCLEAR ATTACK

FINAL REPORT

VOLUME I: DESCRIPTION AND SIMULATIONS

CONTRACT DCPA 01-78-C-0302
WORK UNIT 4341-B

SEPTEMBER 1981

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VOLUME I: DESCRIPTION AND SIMULATIONS

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Acknowledgement

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I. INTRODUCTION

The work described in this report is an extension to, and enhancement of, the dynamic modeling effort under Contract No. DCPA01-78-C-0302. The original effort was very broad in scope, incorporating natural resources at an aggregate, simplified level within a dynamic model of the recovery of the entire U.S. economy following a nuclear attack. The extension (performed under Modification P217-2) focuses on the critical role of natural resources in post-attack recovery at a more detailed and specific level. A Natural Resources Model has been developed, which explicitly represents the production, import, and distribution of key groups of resources and the effects of many resource-related government policies. This model is a tool for assessing the vulnerability of the U.S. economy to various degrees and types of damage to its natural resource sectors. It can be used to analyze the impacts of resource availability, and of U.S. Government natural resource policies, on the process of post-attack economic recovery.

Chapter II of the report contains a summary of the natural resources work, including the results and conclusions that have come from it. Chapter III briefly describes the technical methodology employed. In Chapter IV, the structure of the natural resources model is presented at both the conceptual and equation levels. The use of this model is discussed in Chapter V. Simulations with the model are described in Chapters VI and VII. In the former, a "base line" simulation of the period 1965-2000 is presented and issues of model accuracy are discussed. In the

latter chapter, the results of numerous attack scenario and policy experiments are used to illustrate the breadth of possible uses of the model. The conclusions from this work are contained in Chapter VIII. Other sections of the report describe indicated future research and the references.

At the end of Volume I is an appendix -- "Annotated List of Policies and Scenarios" -- which describes the range of policies that the model is designed to address, and the model parameters used to implement those policies.

A series of technical appendices (bound as a separate volume) contain equation listings of the natural resources model and instructions for running it.

II. SUMMARY

A. Goal of the Project

The goal of this work was to develop a tool for Civil Defense planning in the area of natural resources -- a tool capable of assessing the vulnerability of the U.S. economy to various degrees and types of nuclear attack damage to its natural resource sectors, and a tool for analyzing the impacts of resource availability and U.S. Government natural resource policies on the process of post-attack economic recovery.

That goal can be more precisely defined by listing some of the questions which the effort was intended to explore:

1. What would be the effects of various attack scenarios on U.S. natural resource production, on the balance between resource production and requirements, and on the time it takes to recover to pre-attack production levels?

2. How would post-attack economic recovery be affected by various interruptions of natural resource imports?

3. What would be the effects of various patterns of post-attack inflation on recovery of the natural resource sectors?

4. How would various pre-attack policies and programs (e.g., shelter-building, resource stockpiles, reduced import dependency) affect natural resource prices and availability before and after a nuclear attack?

5. What would be the effects of various post-attack policies and programs (e.g., financial assistance to resource producers, recycling and conservation, wage and price controls, resource rationing)?

6. How would post-attack economic recovery be affected by various priorities for allocating scarce natural resources?

Given the breadth of these questions, the almost infinite variety of scenarios and assumptions one might wish to examine, and the limits of the project, our investigations were by design selective rather than exhaustive. They are intended to illustrate the use of the analysis tool which was developed, and to support a set of thought-provoking and, it is hoped, useful conclusions.

B. Technical Approach

The analysis tool described in this report is a computer simulation model. The technical approach followed in its development, testing, and use is fundamentally the same as was presented in our previous report.[1] We employed the modeling techniques of System Dynamics.[2] The model was programmed in the DYNAMO continuous simulation language.[3]

System Dynamics is a very versatile and robust form of systems analysis. It involves an integration of concepts and methods from control engineering, digital computing, behavioral study of social and economic systems, and modern statistics. The System Dynamics methodology has several strengths which make it particularly well-suited for this project:

1. Emphasis on rich, detailed, realistic representations of decision-making, that are not only applicable under normal conditions but under extreme circumstances, too;

2. Ability to exploit in a common framework diverse types and sources of information, ranging from numerical time series to descriptive literature to the subjective estimates of experts;

3. Absence of methodological constraints that restrict the character of cause-and-effect relationships or types of variables included in a model, thus allowing highly non-linear formulations (e.g., threshold and saturation phenomena) and psychological factors (e.g., morale, future expectations, confidence in government) to be incorporated;

4. Complete "transparency" of results, in the sense that one can trace back to the specific assumptions and elements of model structure which account for any aspect of a simulation; and

5. Cheap and easy simulation, which encourages users to be expansive in their thinking and to explore a wide range of scenarios and policy combinations.

The first three items above mean that System Dynamics models can have sufficient generality to produce reasonable behavior under circumstances which are a dramatic departure from the past. The last two mean that these models can be used in a way which builds confidence in the reasonableness of their results.

C. The Model

The model may be characterized as a dynamic, input-output simulation of the natural resources portion of the U.S. economy. "Dynamic" means that it represents the cause-and-effect interactions among parts of the economy over time. "Input-output" means that the flows of inputs and outputs among the sectors of the model are completely integrated and conserved. They also are calibrated to be consistent with published input-output data.[4] "Simulation" means that the entire model has been expressed in mathematical equations so that the assumptions can be presented unambiguously, and their consequences deduced by automatic computation.

The natural resources portion of the economy is represented as four distinct sectors:

- metallic durable materials
- non-metallic durable materials

- energy products
- non-fuel consumable materials

All sectors consume a portion of their outputs as inputs to their own production (e.g., metal fabricating requires metal, petroleum refining requires crude oil, electric power generation requires fuel). In addition, the three non-energy sectors consume energy. The remainder of natural resource production is consumed by other sectors of the U.S. economy and by government stockpile purchases. The natural resource sectors supplement their domestic production with imports. Aside from natural resources themselves, the natural resources sectors obtain their inputs to production from other sectors of the U.S. economy. Those inputs are labor, capital goods, buildings, and transportation. The natural resource sectors also are connected to one another and to the rest of the economy by various financial linkages. The basic architecture of the natural resources model can be seen in Figure 2.1.

Simulations with the natural resources model generally are started in 1965. Initial values for the intersectoral flows were derived from the U.S. Department of Commerce Bureau of Economic Analysis 1967 input-output table for the U.S. economy.[5] During a simulation, the model continually updates the resource requirements of each sector in response to demand for the sector's output-input shortages (e.g., labor or capital goods), technological advancement, policy assumptions, individual sector financial constraints, and the adjustment of stocks. Therefore, in economics terminology, the model contains a complete variable coefficient input-output structure, with endogenously determined coefficients.

Although numerous details vary from one sector to the next, all four sectors of the natural resources model share a common basic structure.

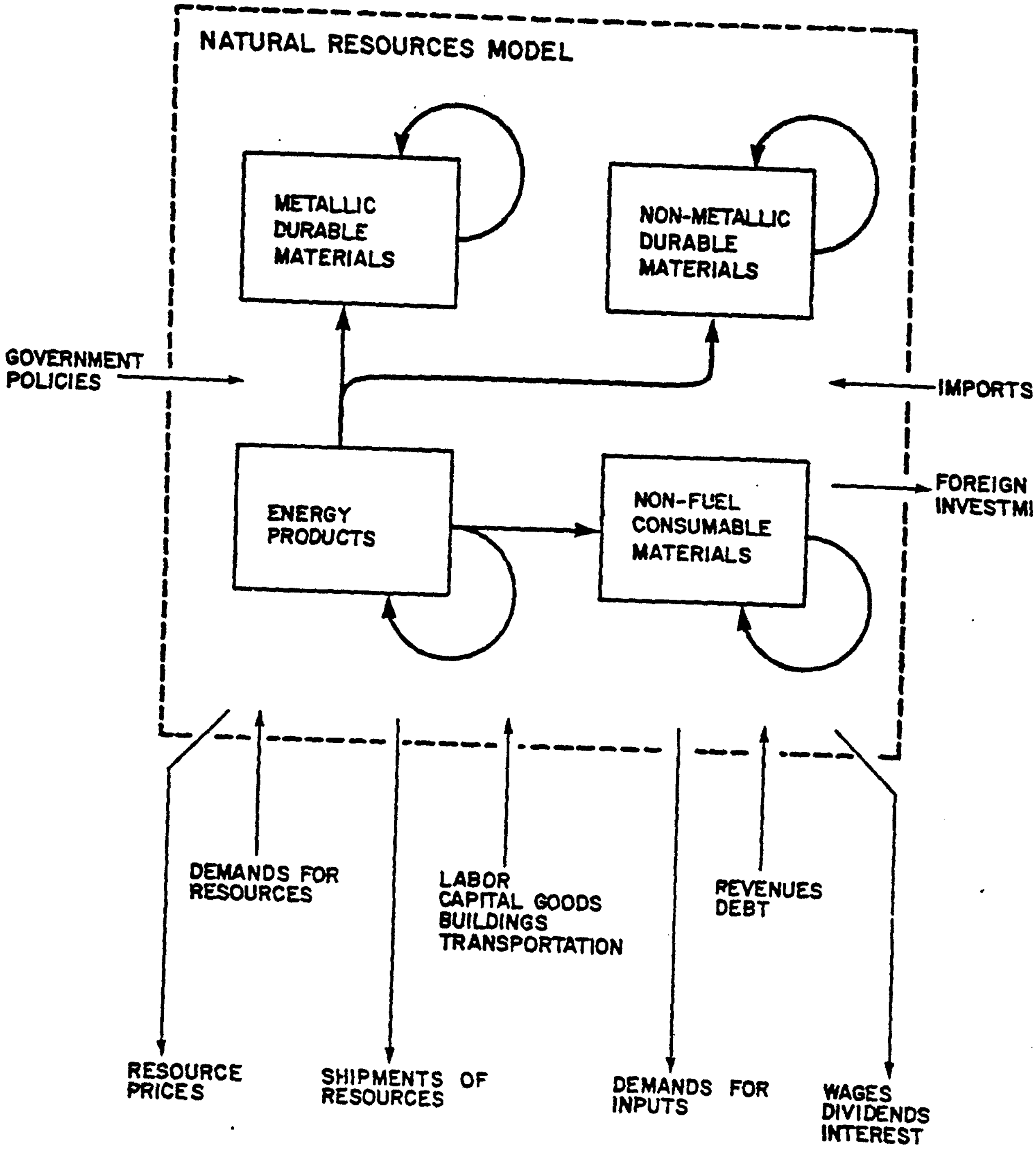


FIGURE 2.1
OVERVIEW OF THE NATURAL RESOURCES MODEL

This basic structure describes the physical and financial stocks and flows, the flows of information, the planning, and the decision-making which are fundamental to any industrial sector of the U.S. economy. In the model, a set of equations for these components is used as a "building block" to create each sector. The idiosyncracies of the four natural resource sectors are expressed through hundreds of parameters, which custom-tailor the building block.

It is essential for the reader to understand the relationship between the natural resources model (which is the subject of this report) and the much larger thirteen-sector U.S. economic recovery model (which is the subject of a separate, previously-issued report).[6] There are really two parts to the relationship: one is developmental and the other is operational. The natural resources work began in June 1979. There followed a period of concurrent development of the two models. As part of the natural resources effort, enhancements were made to the basic sectoral building block common to both models: financial variables, capital investment, prices, and foreign trade were added. Moreover, the natural resources model adopted all major refinements initiated for the U.S. model. An interim version of the natural resources model was integrated into the U.S. model at the time the latter was delivered to FEMA. The attack scenario and policy tests described in the above-mentioned previous report were performed with the thirteen-sector integrated model.

A second phase of work on the natural resources model was undertaken between July 1980 and April 1981. A number of factors, revealed to be important by literature reviews and simulation experiments, were incorporated in the Phase II natural resources model. The Phase II model has achieved a higher degree of historical accuracy in the areas of prices,

financial variables, and imports than did earlier versions of either the natural resources model or the overall U.S. model, including more realistic cyclical behavior. The Phase II natural resources model can be used in two configurations. First, it can operate as a stand-alone four-sector model. Alternatively, it can operate imbedded in the overall U.S. model. All of the simulations described in this report were produced with the four-sector, stand-alone version.

D. Results and Conclusions

Perhaps the most conspicuous, recurring impediment to recovery illuminated by the model is the post-attack cash flow crisis. In the aftermath of a nuclear attack, the natural resource sectors of the U.S. economy will have to undertake massive capital investment programs to rebuild. Clearly, the magnitude of required investment depends on the damage suffered and on the level and recovery rate of resource demands. Nevertheless, under a wide range of attack scenarios, this is the major recovery problem.

The funds available for capital investment are, essentially, from three sources: internal cash flow (i.e., retained earnings plus depreciation), net new borrowing, and government subsidies. The crisis occurs because the investment needs are large, and the internal cash flow of the resource sectors is constrained by:

1. the effects of very high inflation on production costs;
2. the effects of insufficient production capacity on shipments and, hence, on sector revenues;
3. the effect of transportation shortages on shipments and revenues; and

4. the effect of insufficient energy production on energy prices and the costs of energy-consuming sectors.

The debt available to the resource sectors, limited by commercial debt/equity criteria, is not sufficient to make up the difference. In essence, the situation is a classic "Catch 22." More production capacity would generate more revenues and pay for itself in a short time, but the resource sectors do not have enough funds to acquire the capacity.

Policies which break this financial logjam have a very large effect on post-attack recovery. Internal cash flow is augmented by moderate price controls and tax reductions. With controls, there is a delicate balance between reducing a sector's costs and reducing its revenues. Too much of the latter is no good. Government subsidies add funds and, because they also increase sectoral equity, they facilitate more commercial borrowing. Government-guaranteed loans allow the sectors' borrowing to exceed normal commerical debt/equity limits.

The cash flow crisis is very sensitive to both general inflation and energy prices. Government policies which reduce inflation greatly enhance the recovery of the natural resource sectors. There are three ways to attack high energy prices: price controls, government stockpile releases, and resumption of imports. The first is very dangerous because it can worsen the energy shortage and constrain the output of major energy-consuming sectors.

Government stockpiles are most effectively used in a "pump-priming" role. They have to be released rapidly during the first year or two post-attack, but once again, a delicate balancing act is required. If resource prices are depressed too much by stockpile releases, the cash flow crisis is worsened and recovery slowed. The highest-priority resources to

stockpile for "pump priming" are fuels and basic metals such as iron, steel, copper, and aluminum. The esoteric metals are of secondary importance in economic recovery, though critical for a military build-up.

The resumption of natural resource imports, particularly fuels, is very beneficial to recovery. Energy imports reduce consumer costs and facilitate full capacity utilization, which is not possible under many scenarios because of energy shortages.

The energy sector is the keystone in the whole system, and absolutely critical to economic recovery. The energy sector is the single largest consumer of its own outputs (e.g., fuel is required for electric power generation). If the energy sector does not give itself top priority, the self-reenforcing recovery dynamics cannot build up momentum. It takes energy to make energy, and if the energy sector cannot get enough of its own outputs, it is constrained and -- importantly -- so are all of the other major energy consuming sectors. Furthermore, the energy sector is very dependent upon transportation and distribution. For all of these reasons, the energy sector is also our "Achilles heel." The natural resources model shows very clearly what many people fear: a hyper-surgical strike against the energy sector would bring the U.S. economy to its knees for a period of years, in the absence of a large government fuel stockpile or massive energy imports.

The results of the attack scenarios and policy tests confirm the key finding from earlier simulations with the overall U.S. Economic Recovery Model: recovery following a nuclear attack requires reestablishing and maintaining dynamic <u>balance</u> among the interdependent sectors of the economy. Persisting physical imbalances between production and demand cascades into further constraints and imbalances, stimulates worsening

inflation, and fuels the cash flow crisis which ultimately bogs down recovery. Under a wide range of attack scenarios, the natural resource sectors will be sources of dangerous imbalances, and will constrain recovery of the overall U.S. economy. Civil Defense policies such as the ones described above can reduce these imbalances and thus merit serious consideration.

III. METHODOLOGY

The analysis of post-nuclear attack recovery involves great complexity and uncertainty. Dealing with these complexities imposes several requirements on the analytic method to be used. These requirements are discussed below, in Section A. Section B describes the techniques (known collectively as "System Dynamics") used to meet the requirements. Section C summarizes how the methods of System Dynamics satisfy the requirements. A brief comparison of System Dynamics with the traditional methods of econometrics is given in Section D.

A. Methodological Requirements

Any attempt to assess civil defense policy by estimating the likely path of post-nuclear attack recovery must, by the nature of the problem addressed, meet several constraints and requirements. These requirements are discussed below.

a. Realistic. The method should be able to take into account any kind of cause and effect believed to be operating in the real economic-political system. For example, the method must be able to represent both reality and perceptions, and the biases, lags, and distortions that separate them. The method should not presuppose simplifications or limiting conditions, such as linearity or equilibrium, which might save on computation but sacrifice realism and, therefore, usefulness.

b. Dynamic. Some problems are amenable to static analysis, requiring the consideration of a single, unchanging condition, but post-attack recovery is not one of them. The choice of civil defense policies depends not only on where the socio-economic system ends up, but also on how it got there and how long the recovery took. Therefore, the method

must be able to trace the evolution of cause and effect over time.

c. Nonlinear. The methods must be able to represent, on the "micro" level, saturations, limiting factors, multiplicative effects, and other realistic but nonlinear features. Such phenomena, acting in concert, may well imply a different character of recovery, not merely proportional changes in recovery time, as a consequence of different civil defense policies. The choice of policy may, indeed, determine whether recovery takes place at all.

d. Iterative. The uncertainties of the post-attack recovery require that alternative scenarios be considered. Scenarios may vary due to different possible values of uncertain parameters (e.g., nature of the attacks, efficacy of CD efforts, political conditions following an attack). Therefore, the method must be able to conveniently test the consequences of varying assumptions and to support an iterative process of defining CD goals, analyzing policy requirements, and refining goals.

e. Transparent. The analysis must be easily accessible to inquiry. It should always be possible to determine why the result occurred. The time-evolution of any variable should be obtainable, and each variable should clearly relate to something real.

f. Adaptive. Both the complexity and the uncertainty surrounding the post-attack recovery problem require that the analysis framework be easy to modify. Alternative assumptions or structures may arise as 1) a correction to a discovered error, 2) an elaboration or more detailed treatment of a part shown to be important, or 3) an alternative input parameter value, or structure chosen from a range of possible but uncertain values. Regardless of the motive, changes should be easily accommodated by the method.

g. Statistically Compatible. The structure and results of the analysis should be amenable to statistical techniques, such as the estimation of parameters, testing for consistency with available knowledge, and computing confidence bounds on the results.

h. Information-Compatible. The analysis should be capable of accepting all relevant information regardless of form. It should be able to combine numerical data, descriptive assessments, and expert opinions in a single, consistent framework. Particularly, it should be able to use the results of other analyses germane to civil defense and post-attack recovery.

i. Testable. The analysis and results should be amenable to both formal and informal tests of validity. To some extent,

this follows from the preceding requirements that the analysis be transparent (e) and statistically compatible (g). However, the assessment of validity goes beyond mere inspection and summary statistics.

B. The System Dynamics Method

System Dynamics is the methodology employed in this analysis of post-nuclear-attack economic recovery. System Dynamics provides a conceptual discipline and supporting computer software for the analysis of complex, nonlinear dynamic systems. In terms of flexibility, absence of inherent methodological constraints, user-orientation, emphasis on causality, sophistication in dealing with interactions over time, and pure cost/effectiveness, System Dynamics represents the state-of-the art in predictive methods. It is the logical evolutionary extension of earlier approaches to prediction.

The first evolutionary stage of predictive methods was the subjective "expert opinion" by knowledgeable individuals. Such nonquantitative projections are based on intuitive judgment and personal experience. The next stage was the development of naive forecasting models. These represent initial attempts at quantitative prediction such as trend extrapolation. The third evolutionary stage was simple correlative models. Here, forecasting is based on the presumption that simple statistical patterns observed in the past will continue in the future. Next came complex multivariate econometric forecasting. These large-scale statistical models are inferred from time-series data; their structures are developed based on consideration of "best fit" to historical data, and are generally restricted to variables for which precise numerical data exist.

System Dynamics is fifth stage in the evolution of predictive methods. It has evolved at the Massachusetts Institute of Technology and

Pugh-Roberts Associates, Inc. over the past twenty years. Several interrelated developments made this possible. These have included the development of information feedback control theory (also the basis of cybernetics), large-scale digital computers that permit rapid and inexpensive simulation of complex systems, a clearer understanding of human decision-making processes, and statistical techniques for defining and testing complex system models under conditions of incomplete and inaccurate data. System Dynamics integrates these developments into one framework.

Reflecting its origins in servo-mechanics and engineering control theory, System Dynamics views an industrial, social, or economic system as composed of three primary components: "states" of the system, rates of change, and information networks. "State variables" (also known as "stock variables") describe the condition of the system and accumulations of system resources. For example, state variables could include material inventories, labor pools, money, and capital equipment. States also include qualitative attributes of system resources, e.g., the skills, morale, and state of health of a labor force, and prevailing perceptions and attitudes. Another example of a a system state is the level of public confidence in Civil Defense programs. Rates of change are the flows of the system such as receipt and payment of money, the acquisition and disposal of capital equipment, changes in perceptions, or acquisition of skills. These flows act to change the system states over time. The third component of a system is its information network, representing perceptions, judgments, and decisions. Through this complex network, information describing past and current states of the system is used by decision makers such as consumers, corporate executives, and government officials. Based on this information, the decision makers take actions that tend to change the rates

of the system and, subsequently, the future states. For example, corporate executives collect information on the supply-demand balance and risk of a market and the financial condition of their company in terms of debt levels, equity, and cash flow, and then make investment decisions. These investments create a flow of production capacity coming on-stream. This new capacity then affects the supply-demand balance, the cash flow of the company, the perceived risk, and the other factors that determine future investment decisions. Public sector officials also tend to respond in this manner to information describing economic and social conditions.

Given this basis for viewing a system, it is possible to develop a "conceptual model" describing the structure and interrelationships of the system being investigated. The conceptual model takes the form of diagrams and descriptions which identify the system states, the rates of change affecting these states, and the information feedback network of the system. The qualitative relationships of the conceptual model are then quantified in equations, defining numerically the decision rules which generate the system's rates of change. The quantification includes explicit representation of the delays involved in collecting data, making decisions, and in initiating action. The equations are implemented on a digital computer and then used to simulate and forecast the behavior of the system. The equations in this model are written in the DYNAMO language that was developed at M.I.T. and at Pugh-Roberts Associates, Inc. for System Dynamics analysis. (Pugh-Roberts Associates distributes, supports, and updates DYNAMO.) The model had been used to develop a "base" simulation and a set of alternate scenarios. The base simulation provides a benchmark against which to measure the impact of alternate policies, priorities, or attack scenarios.

Alternative scenarios may also be used to examine the consequences of changes in parameters or structural assumptions, where there is uncertainty about their true value. Such "sensitivity testing" constitutes an informal statistical analysis and estimation of the model. More rigorous statistical techniques have recently become feasible for models of the System Dynamics type. The statistical methods use optimal filtering and unconstrained optimization techniques to extract from imperfect data the most likely values of system parameters, states, and structure. The methods also permit the statistical assessment of model validity on a "full information" basis. These statistical routines are incorporated in the GPSIE (General Purpose System Identifier and Evaluator) and DYNASTAT computer programs, both developed, maintained, and distributed by Pugh-Roberts Associates, Inc.

The facility for comparing the effects of alternate policies and scenarios and dealing with uncertainty makes System Dynamics a useful technique for planning civil defense and preparedness policies. The model described in subsequent chapters of this report indicate that complex systems containing even many hundreds of parameters can be represented successfully. The technique of identifying system states, rates of change, and information flows is also a useful way of organizing knowledge and developing an understanding of how the system components interact. The overall value of the System Dynamics approach, therefore, is not just in the simulations and forecasts but also in the analysis that provides an understanding of why the system behaves as it does.

System Dynamics has several strengths for addressing complex issues in large-scale social and economic systems. First, it provides a framework

for identifying and understanding the complex network of information-linkages, financial and physical flows, and behavioral activities that connect the various sectors of the system. Second, it provides a set of principles for developing mathematical equations that can be implemented on a computer in order to simulate the behavior of the system. Third, the equations provide a laboratory test bed for assessing various alternative assumptions, policy proposals, and what if questions. System Dynamics has been quite successful in representing complex socio-economic behavior and decisions, investment and resource allocation processes, and in combining physical, financial, technical, political, and psychological variables into consistent, mathematical relationships.

C. How System Dynamics Meets the Methodological Requirements

We now review the methodological requirements and describe how the System Dynamics techniques meet each requirement.

a. Realistic. System Dynamics is very flexible. It imposes no inherent methodological constraints on the analysis process. Any type of relationship which can be described by ordinary English, by a curve, or by a mathematical expression can be included in a System Dynamics model. Any type of variable, from "hard" physical ones to very "soft" psychological ones, and any type of information, from statistical time series to educated guesses, can be included.

b. Dynamic. The System Dynamics methodology inherently leads to explicit representation of the causes and effects ("dynamics") of change. In addition, the DYNAMO software automatically checks models for ambiguous or redundant definitions of the dynamics of the system. DYNAMO also detects and reports as errors implicit assumptions of equilibrium or undefined relationships.

c. Nonlinear. Any kind of nonlinearity can be represented in a System Dynamics model. DYNAMO offers convenient facilities for nonlinear representations, includng a lookup-table function for expressing nonlinear relationships of arbitrary shape. The model makes extensive use of these facilities to deal with nonlinear phenomena.

d. Iterative. The capabilities of System Dynamics, as this list of requirements implies, allow great generality and complexity in both models and analysis. Often, therefore, closed-form techniques (such as ordinary least squares) are inapplicable, and iterative techniques must be used for estimation, sensitivity analysis, and policy evaluation. The DYNAMO software allows efficient use of iterative techniques, including the convenient "manual" testing of alternative scenarios and assumptions.

e. Transparent. The DYNAMO simulation and documentation software make it especially easy to examine and evaluate both models and results. The model equations are written in the order which maximizes clarity, since DYNAMO automatically resequences the equations for computation. Documentation facilities in DYNAMO allow special listings (such as the one in Appendix D) which juxtapose definitions and units of each variable with each equation in which the variable occurs. Any variables in the model may be plotted or printed in a variety of formats, making it easy to determine why the simulations perform as they do.

f. Adaptive. The software and techniques of System Dynamics allow prompt and efficient corrections and modifications to be made to a model. DYNAMO quickly informs the user whether a modification has resulted in undefined or multiply-defined variables, and also flags any variable left unused.

g. Statistically Compatible. The techniques and software used by Pugh-Roberts Associates, Inc. permit a wide range of statistical approaches, in an environment of nonlinear models, uncertain inputs, sparse data, noisy data, and uncertain parameters.

h. Information-Compatible. The model-conceptualization and equation-writing techniques employed by Pugh-Roberts Associates allow the representation of any kind of information in the model, including descriptive literature, constraining factors, accepted mathematical "laws", and other models, in addition to the use of numerical, time-series data. The analytical techniques of System Dynamics may also be used to specify what additional information would allow maximum improvement in the accuracy of the results.

i. Testable. System Dynamics models are open to a wide range of informal and mathematical tests of validity. The model can be readily examined for internal consistency, pushed to

limits, explored with alternative scenarios, and subjected to formal statistical tests of consistency with data.

The specific model structure embodying the above properties is described in Chapter VI and is completely defined by the equations and definitions in Volume II. The remaining sections of Chapter III describe how the methods of System Dynamics compare with those of the previously-used techniques of econometrics, and how the use of the System Dynamics methods have been organized to develop the present model.

D. Relationship with Econometrics

Because most previous recovery models are econometric, it is useful to highlight the specific ways in which the System Dynamics methodology used in this study differs from the widely-used techniques of econometrics. Between the two methodologies there are many similarities and several important differences.

Similarities. Both System Dynamics and econometrics are concerned with the creation of "models" — systems of equations which describe some real-world process, such as an economy. Both methodologies try to take advantage of both theory and data in constructing equations and setting the numerical values of parameters in those equations. Both methodologies use the model equations to simulate the behavior of the real economy being modeled. Finally, and importantly, both methodologies consist of a collection of specific techniques and approaches, not a single mathematical tool. Therefore, both methodologies vary in their definition and practice according the the different skills and preferences of the various people who describe themselves as using System Dynamics or econometrics. Because

of variation in practice within each methodology, and because of some common mathematical underpinnings, there is considerable overlap of practice among some users of the two methodologies.

Differences. Despite the similarities between System Dynamics and econometrics, and the sometimes-fuzzy boundary between them, there are important distinctions, which motivate the approach taken in this study. Each of the following paragraphs describes a significant difference between System Dynamics and econometrics. The discussion is by no means all-inclusive, but is intended to highlight differences that are particularly relevant to the problems of analyzing trans-attack and post-attack behavior of an economy. Also mentioned are differences in terminology or practice that are likely to cause the misinterpretation of the results of one methodology when viewed by practitioners of the other methodology.

Whole-System Testing and Parameter Development. Econometric models are generally built one equation at a time, with each equation's parameters immediately calibrated to fit the available time-series data. After all the equations have been so calibrated ("estimated"), they are combined and simulated. When this is done, the inputs to each equation, which were exclusively historical data when the equations were developed, are replaced by the outputs of other equations. In contrast, all the equations of System Dynamics models are assembled for simulation very early in the process, with parameters calibrated simultaneously by comparison between many information sources and the behavior of the entire system of equations. Therefore, the inputs of each equation are, from the beginning, supplied by the output from other equations. System Dynamics models do not require time series data to get to the point where simulation is possible, and hence may easily contain variables for which there is no data. This

difference is the source of the convenient ability to represent psychological and other "soft" variables in a System Dynamics model.

<u>Finer Time-Detail</u>. The relative independence of System Dynamics equations from time-series data (described in the preceding paragraph) also allows Systems Dynamics models to employ short time divisions. Most econometrics models update their simulation solutions in steps of three months or one year, because those are the intervals at which most economic data are available. The System Dynamics model described in this report may be solved in much shorter time steps. The normal solution interval is three weeks, but this interval may be reduced even further by the simple adjustment of a single input to the model. The System Dynamics model can therefore accurately simulate important effects which happen in a few weeks (such as inventory depletions after a nuclear attack).

<u>No Assumed Equilibrium</u>. Because their equations are solved at longer intervals, econometric models often make simplifying assumptions about the behavior of the system between solutions. One often-made assumption is that markets and other aspects of the economy are in equilibrium (that is, that the variables are in a stable state). System Dynamics models, using shorter time intervals, are able to explicitly represent the forces that may push an economy toward or away from equilibrium. If conditions are normal, then the two approaches may yield the same results (that is, the econometric model is assumed to be in equilibrium; the System Dynamics model simulates the process and <u>goes</u> to equilibrium). However, in highly unbalanced conditions, such as during and after a nuclear attack, it is most unrealistic to assume a permanent condition of equilibrium. System Dynamics models have the advantage of easily representing all possible

conditions of the system, and the transitions among them, especially in times of severe disequilibrium.

Robustness and Realism. Because System Dynamics models are assembled and simulated first, and adjusted to data second, a great deal of attention is paid to the correctness of each equation under all possible values of its parameters and inputs. And because the System Dynamics methods impose no constraints on the mathematical form of the equations, it is feasible to design such robust, realistic equations. In contrast, the single-equation estimation techniques of econometrics impose constraints on the form of the equations (such as "linearity in the parameters"). These restricted-form equations are often adequate to describe economic systems operating in the relatively narrow, normal range of the historical data, but the equations may give absurd results for extreme inputs, negative growth rates, or sudden changes. The restricted equation forms of econometrics may, therefore, yield absurd behavior in simulating the trans- and post-nuclear attack economy. Indeed, such models have been observed to yield negative outputs, rapid oscillations ("ringing"), and similar mathematical misbehavior when subjected simulated nuclear damage. The unrestricted equation forms of System Dynamics impose no constraints on the realism of the models, even under extreme conditions.

IV. STRUCTURE OF THE NATURAL RESOURCES MODEL

In this chapter, the structure of the natural resources model is presented at several levels of technical detail. First, an overview is established so that the reader can visualize the model's basic architecture and how it relates to the much larger thirteen-sector model discussed in our report Development of a Dynamic Model to Evaluate Recovery Following a Nuclear Attack.[1] Next, the components of an individual natural resource sector are described. Important equations from the natural resources model are presented and explained. Finally, the most significant external inputs to the model are reviewed. Appendices to this report contain instructions for reading equations in the DYNAMO computer simulation language[2] and a complete listing of the model.

A. Overview of the Model

The model may be characterized as a dynamic, input-output simulation of the natural resources portion of the United States economy. "Dynamic" means that it represents the cause-and-effect interactions among parts of the economy over time. "Input-output" means that the flows of inputs and outputs among the sectors of the model are completely integrated and conserved. They also are calibrated to be consistent with published input-output data.[3] "Simulation" means that the entire model has been expressed in mathematical equations so that the assumptions can be presented unambiguously, and their consequences deduced by automatic computation.

The natural resources portion of the economy is represented as four distinct sectors:

- o metallic durable materials
- o non-metallic durable materials
- o energy products
- o non-fuel consumable materials

The metallic durable materials sector represents the mining and primary manufacture of metals. The sector's output includes ores, metals, and basic fabricated metal shapes. Durable materials are defined as those which are practically recoverable from the economy. They are represented separately from "consumable materials" (see definition below) in order to allow a more accurate simulation of recycling. The non-metals durable materials sector represents the production of all other durable materials. This sector includes quarrying, earth minerals mining, and manufacturing of stone, clay, and glass products.

The energy sector represents the production of fuels and electricity. Coal mining, crude petroleum and natural gas extraction, petroleum refining, and the generation of electricity are included in this sector. The non-fuel consumable materials sector represents all consumable materials not involved in energy production. Consumable materials are defined as those which "go up the stack", degrade relatively quickly, are dissipated into the environment, or otherwise are difficult to recycle. Chemicals, fertilizer, textiles, lumber, paper, plastics, paint, rubber, and leather are produced by the non-fuel consumable materials sector.

The specific industries in each of the four natural resource sectors,

listed according to the classification system used by the U.S. Department of Commerce for reporting inter-industry transactions,[4] are shown in Figure 4.1.

The sectors of the model are interconnected in an input-output structure. Part of the physical output of each sector is consumed within the sector as an input to production, and part shipped to and consumed by other sectors. All physical flows of products in the model are conserved. Thus, a shortfall in production by any one sector becomes input shortages for other sectors (although this effect is buffered by producer inventories, government stockpiles, and imports).

The basic architecture of the natural resources model can be seen in Figure 4.2. All sectors consume a portion of their outputs as inputs to their own production (e.g., metal fabricating requires metal, petroleum refining requires crude oil, electric power generation requires fuel). In addition, the three non-energy sectors consume energy. The remainder of natural resource production is consumed by other sectors of the U.S. economy and by government stockpile purchases. The source of these demands from "other sectors" and, more generally, the relationship between the natural resources model and the "rest of the economy," are discussed below.

Returning to Figure 4.2, the natural resource sectors supplement their domestic production with imports. The extent to which this occurs depends on the adequacy of domestic production, import prices, and the availability of imports. If the financial incentives are favorable in that direction, the natural resource sectors can invest in overseas production rather than produce more domestically. Aside from natural resources themselves, the natural resources sectors obtain their inputs to production from other

Industries Included in the Metallic Durable Materials Sector

Industry Number	Industry
5	Iron and ferroalloy ores mining
6	Nonferrous metal ores mining
37	Primary iron and steel manufacturing
38	Primary nonferrous metal manufacturing
83	Scrap, used and secondhand goods

Industries Included in the Non-Metallic Durable Materials Sector

Industry Number	Industry
9	Stone and clay mining and quarrying
35	Glass and glass products
36	Stone and clay products

FIGURE 4.1

Industries Included in the Energy Products Sector

Industry Number	Industry
7	Coal mining
8	Crude petroleum and natural gas
31	Petroleum refining and related industries
68	Electric, gas, water and sanitation services

Industries Included in the Non-Fuel Consumable Materials Sector

Industry Number	Industry
10	Chemical and fertilizer mineral mining
16	Broad and narrow fabrics, yarn and thread mills
17	Miscellaneous textile goods and floor coverings
20	Lumber and wood products, except containers
21	Wooden containers
24	Paper and allied products, except containers
25	Paper board containers and boxes
26	Printing and publishing
27	Chemicals and selected chemical products
28	Plastics and synthetic materials
29	Drugs, cleaning and toilet preparations
30	Paints and allied products
32	Rubber and miscellaneous plastics products
33	Leather tanning and industrial leather products
39	Metal containers
79	State and local government enterprises

FIGURE 4.1 (cont'd)

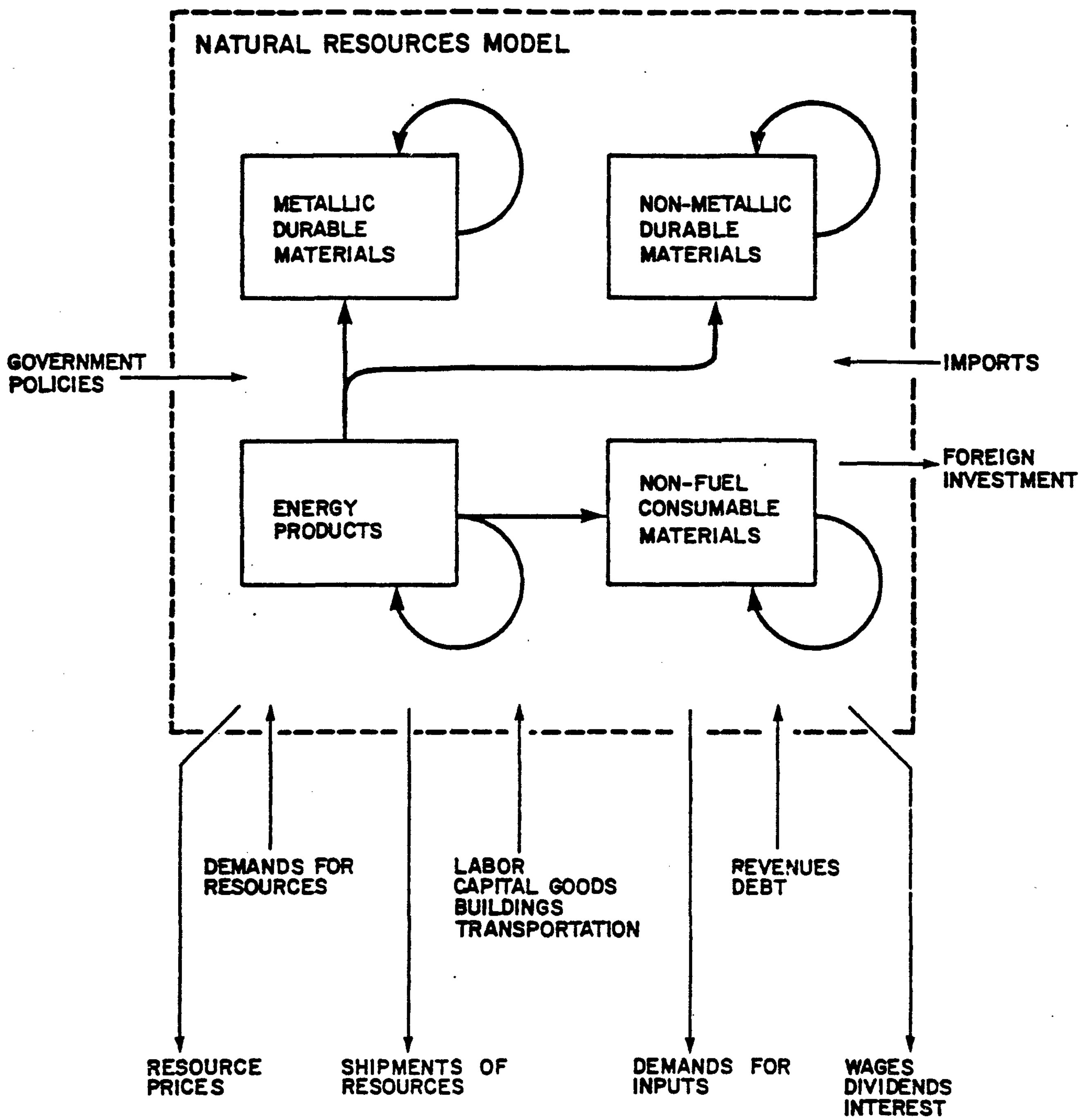


FIGURE 4.2

OVERVIEW OF THE NATURAL RESOURCES MODEL

sectors of the U.S. economy. Those inputs are labor, capital goods, buildings, and transportation.

The natural resources sectors are also connected to one another and to the rest of the economy by various financial linkages. Natural resource prices affect demands. Deliveries generate revenues. Wages, dividends, and interest are paid. Debt is obtained for working capital and investment in capacity, subject to limits of credit worthiness and availability. Finally, the natural resources sectors are impacted by a variety of government policies: taxation, interest rates, trade restrictions, environmental regulations, stockpiling programs, allocation or rationing of scarce materials, wage and price controls, etc.

Simulations with the natural resources model generally are started in 1965. Initial values of the intersectoral flows were derived from the U.S. Department of Commerce Bureau of Economic Analysis 1967 input-output table for the U.S. economy.[5] During a simulation, the model continually updates the resource requirements of each sector in response to demand for the sector's output, input shortages, (e.g., labor or capital goods), technological advancement, policy assumptions, individual sector financial constraints, and the adjustment of stocks. Therefore, in economics terminology, the model contains a complete variable co-efficient input-output structure, with endogenously determined coefficients.

B. The Basic Sectoral Building Block

Although numerous details vary from one sector to the next, all four sectors of the natural resources model share a common basic structure. This basic structure describes the physical and financial stocks and flows, the flows of information, the planning, and the decision making which are fundamental in any industrial sector of the U.S. economy. Its components include:

- o Finance and accounting
- o Production planning
- o Actual production
- o Ordering and acquisition of inputs to production
- o Capital investment
- o Allocation of sectoral output
- o Pricing
- o Foreign trade
- o Government policies

In the model, a set of equations for these components is used as a "building block" to create each sector. The idiosyncrasies of the four natural resource sectors are expressed through hundreds of parameters, which custom tailor the building block. Many of the parameters are discussed later in this chapter.

The contents of the basic sectoral building block are summarized in Figure 4.3. The shaded portion of the diagram highlights the physical variables which combine to produce a sector's output. Production is a function of the labor in the sector, its productivity, the adequacy of capital goods, and the adequacy of raw materials. The acquisition of labor and raw materials is determined by planned production and, of course, by their availability. Not shown in this diagram (to keep the figure simple and easily comprehended) but certainly in the building block is the effect of raw material prices on consumption and recycling.

The remainder of Figure 4.3 relates primarily to financial variables and decisions. The key decisions represented in the building block have to

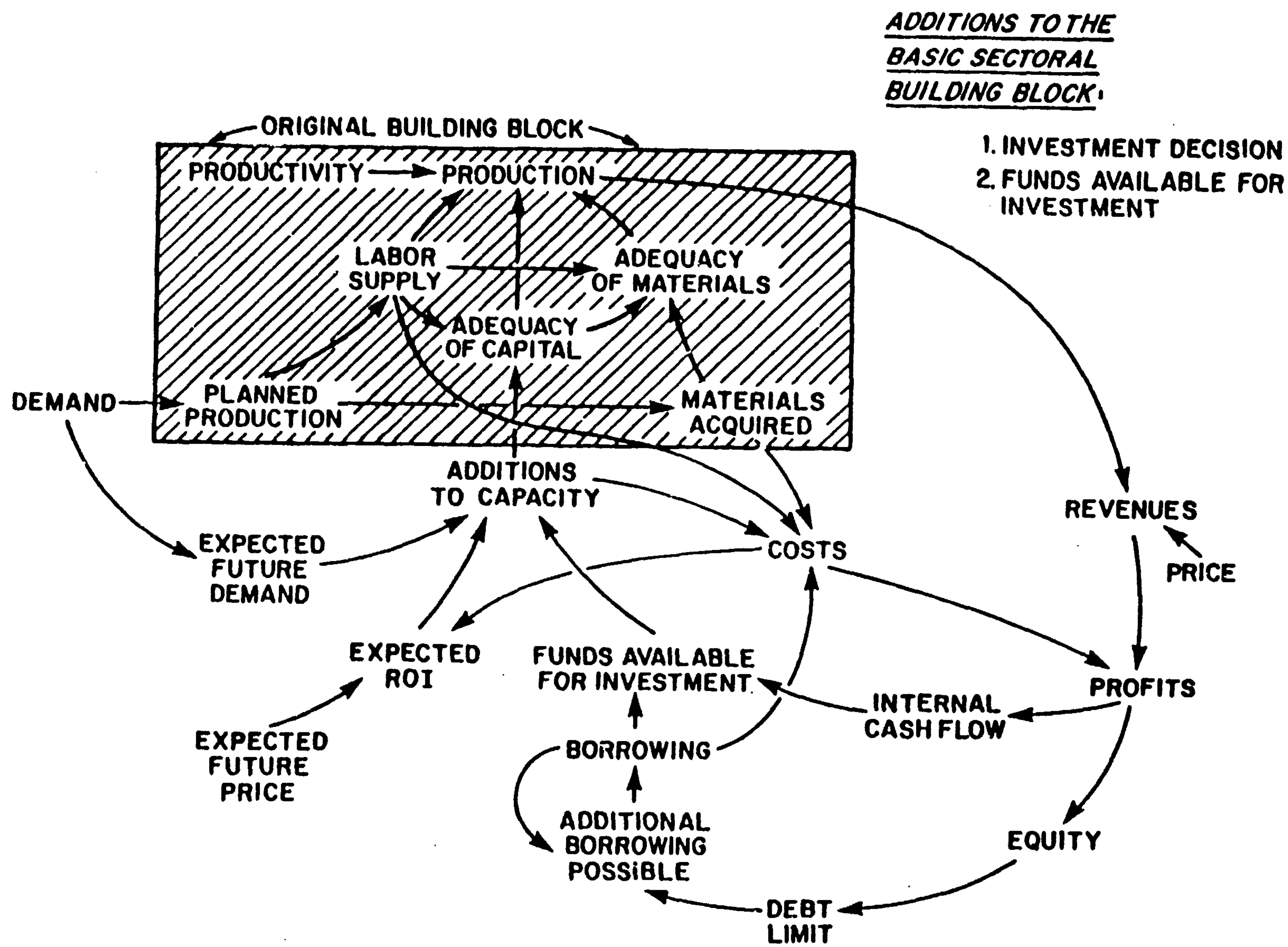

ADDITIONS TO THE BASIC SECTORAL BUILDING BLOCK:
1. INVESTMENT DECISION
2. FUNDS AVAILABLE FOR INVESTMENT
ORIGINAL BUILDING BLOCK
PRODUCTIVITY
PRODUCTION
LABOR SUPPLY
ADEQUACY OF MATERIALS
ADEQUACY OF CAPITAL
DEMAND
PLANNED PRODUCTION
MATERIALS ACQUIRED
ADDITIONS TO CAPACITY
REVENUES
PRICE
EXPECTED FUTURE DEMAND
COSTS
EXPECTED ROI
FUNDS AVAILABLE FOR INVESTMENT
PROFITS
INTERNAL CASH FLOW
BORROWING
EXPECTED FUTURE PRICE
ADDITIONAL BORROWING POSSIBLE
EQUITY
DEBT LIMIT

FIGURE 4.3

do with additions to capacity, borrowing, pricing, and imports. These decisions are highly interrelated, as one can see from the diagram. Additions to production capacity result from capital investment. The desired rate of investment is determined by expected future demand for the sector's output and expected return on investment (ROI). The actual investment rate, however, is constrained by the funds available from internal cash flow and net new borrowing. Internal cash flow comes from profits and depreciation, minus dividends paid. The amount of additional borrowing possible depends, in the building block, on a sector's debt/equity ratio as a measure of debt carrying capacity.

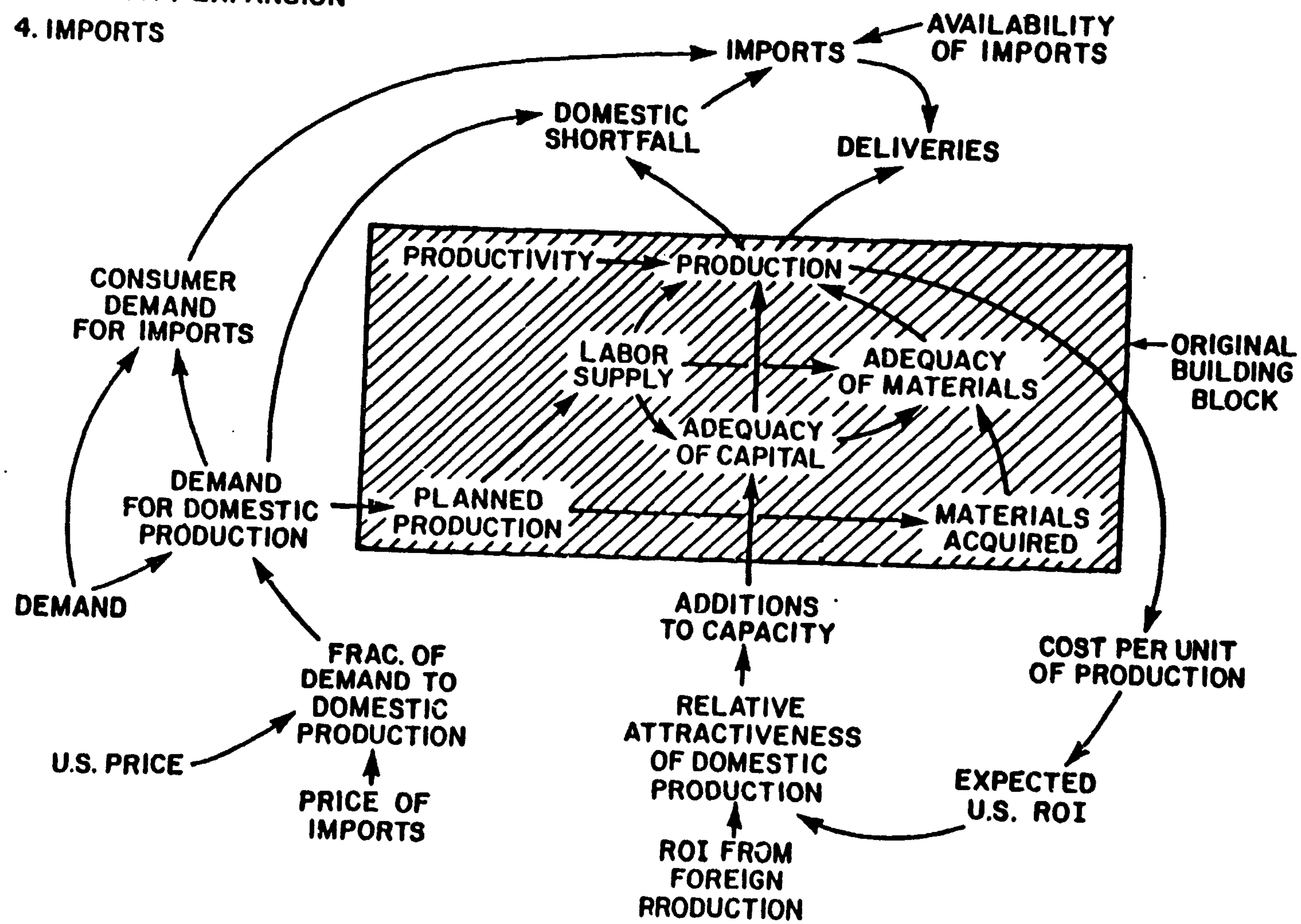
Built in to the basic building block structure are circular relationships which are fundamental to industrial growth and stagnation. For example, increased production can lead to increased revenues, internal cash flow, debt capacity, additions to production capacity, and, ultimately, production. On the other hand, increased borrowing and additions to capacity can increase costs (more interest and depreciation), reduce expected ROI and, thereby, reduce the financial attractiveness of further capital investment.

In the building block, resource prices depend on costs, a real rate of return on investment sought by producers, and market conditions as indicated by supply/demand balance. Here, there exists another important circular relationship. Excess production can depress price, stimulate additional demand, reduce capacity expansion, and after some delay restore a reasonable supply/demand balance.

Figure 4.4 summarizes the portion of the basic sectoral building block which relates to foreign trade and investment. Natural resource imports depend on prices and availability. The fraction of U.S. demand directed to

ADDITIONS TO THE BASIC SECTORAL BUILDING BLOCK:

3. LOCATION DECISION FOR CAPACITY EXPANSION
4. IMPORTS



FIGURF 4 4

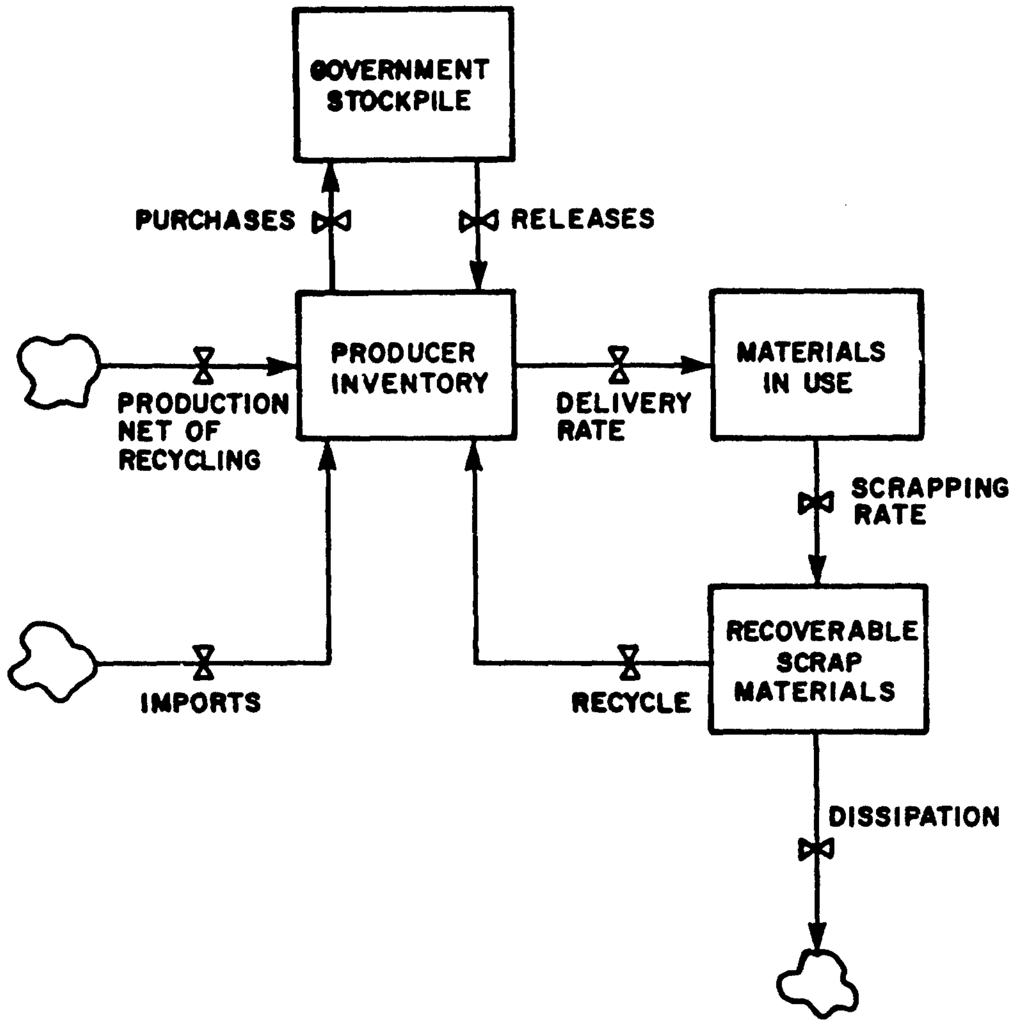
domestic production is a function of the U.S. price relative to the price of imports. That fraction defines the consumer demand for imports. Actual imports can be higher if there is a shortfall of domestic production below demand; imports can be lowered by the unavailability of resources from abroad. As shown in the lower portion of the figure, additions to production capacity in the U.S. are affected by the relative ROI expected from domestic and foreign operations.

Finally, Figure 4.5 shows the stocks and flows of the resource itself, as represented in the basic sectoral building block. The resource initially resides in the ground, as part of proven and probable reserves.[6] "Production" involves extraction, processing, and primary fabrication, adding to producer inventories. Imported resources also flow into producer inventories in this model. Deliveries from the resource sectors to consumers add to the total material in use for durable materials. Consumable material are assumed to be immediately lost into the environment. As the goods in which durable materials are incorporated wear out or are destroyed, the material becomes scrap that either can be recycled or ultimately is dissipated and lost.

Figures 4.3, 4.4, and 4.5 provide a simplified overview of the basic sectoral building block of the natural resources model. That was their intent. Later sections of this chapter will discuss each component of the building block in detail, with additional diagrams and an exposition of important equations and numerical assumptions.

C. Relationship to the U.S. Economic Recovery Model

It is essential for the reader to understand the relationship between the natural resources model (which is the subject of this report) and the



STOCKS AND FLOWS OF A RESOURCE

FIGURE 4.5

much larger thirteen-sector model discussed in our previous report, Development of a Dynamic Model to Evaluate Recovery Following a Nuclear Attack (November 1980). The relationship between these two models is, indeed, somewhat confusing. There are really two parts to the relationship: one is developmental and the other is operational.

The natural resources model has been developed under an extension to the contract which originally supported development of the U.S. recovery model. Work on the U.S. recovery model began in October 1978. This model considers the U.S. economy as a whole. The initial version incorporated natural resources at an aggregate, highly simplified level. The purpose of the extension of work was to focus on the critical role of natural resources in post-attack recovery at a more detailed and specific level, by adding explicit representations of key categories of resources and resource policies into the recovery model. The objective was to create a means for evaluating the effect of natural resource policies on recovery following a nuclear attack. The natural resources work started in June 1979.

There followed a period of concurrent development of two models: a four-sector natural resources model and a thirteen-sector overall U.S. model. Development of the two models has proceeded as parallel, but highly interrelated efforts. The natural resources model started with the "production building block" from the overall U.S. model (the shaded portions of Figures 4.3 and 4.4) as it existed in September 1979. As part of the natural resources effort, enhancements were made to the basic sectoral building block common to both models: financial variables, capital investment, prices, and foreign trade were added. These features were implemented in all relevant sectors of the U.S. model in April and May 1980. Moreover, the natural resources model adopted all major refinements

initiated for the U.S. model. Examples of those include the representations of technological change and attack damage. Thus we ensured that: (a) lessons learned and refinements made in the course of developing one model were systematically transferred to the other; and (b) that the two models were compatible in both their conceptual designs and equation structures.

Because of the specific problem focus of the natural resources model, government stockpiles and effect of stockpile purchases and releases on resource markets were added to that model. An interim version of the natural resources model (referred to as the Phase I model) was integrated into the U.S. model at the time the latter was delivered to FEMA. The attack scenario and policy tests described in our report <u>Development of a Dynamic Model to Evaluate Recovery Following a Nuclear Attack</u> were performed with the thirteen-sector integrated model (incorporating the Phase I natural resources model).

A second phase of work on the natural resources model was undertaken between July 1980 and April 1981. A number of factors, revealed to be important by literature reviews and simulation experiments, were incorporated in the Phase II natural resources model during the fall of 1980:

- the effects of resource depletion on capital investment requirements and operating costs in the natural resources sectors;
- the effects of environmental regulations on those same investment requirements and costs;
- the effects of resource prices and availability on recycling of durable materials, and the effects of recycling on the labor, capital, and energy requirements for resource production;
- the effects of import prices on the U.S. domestic prices for natural resources;

- more realistic representation of attack damage, including the concept of "disabled", though not destroyed capital and the destruction or contamination of resource reserves; and
- a wider range of policy "levers" to represent such possible government actions as rationing, the buildup of strategic stockpiles during a pre-attack mobilization and the hardening of stockpiles.

Subsequent work on the Phase II model resulted in more enhancements. These include:

- a dynamic formulation for the time to perceive costs and prices, where the delay depends on the inflation rate (a highly inflationary environment decreases the perception time, as decision-makers are more aware of cost and price changes, and react more sharply to avoid financial loss);
- the effects of both import price and availability on import demands;
- the linkage of post-attack interest rates to post-attack inflation; and
- development of a "default system" of linked assumptions that can eliminate the need to define many of the inputs of a typical attack scenario.

The Phase II natural resources model has been used to analyze the effects of resource availability, and of government natural resource policies, on the process of post-attack economic recovery. All of the simulations in this report were performed with the Phase II natural resources model.

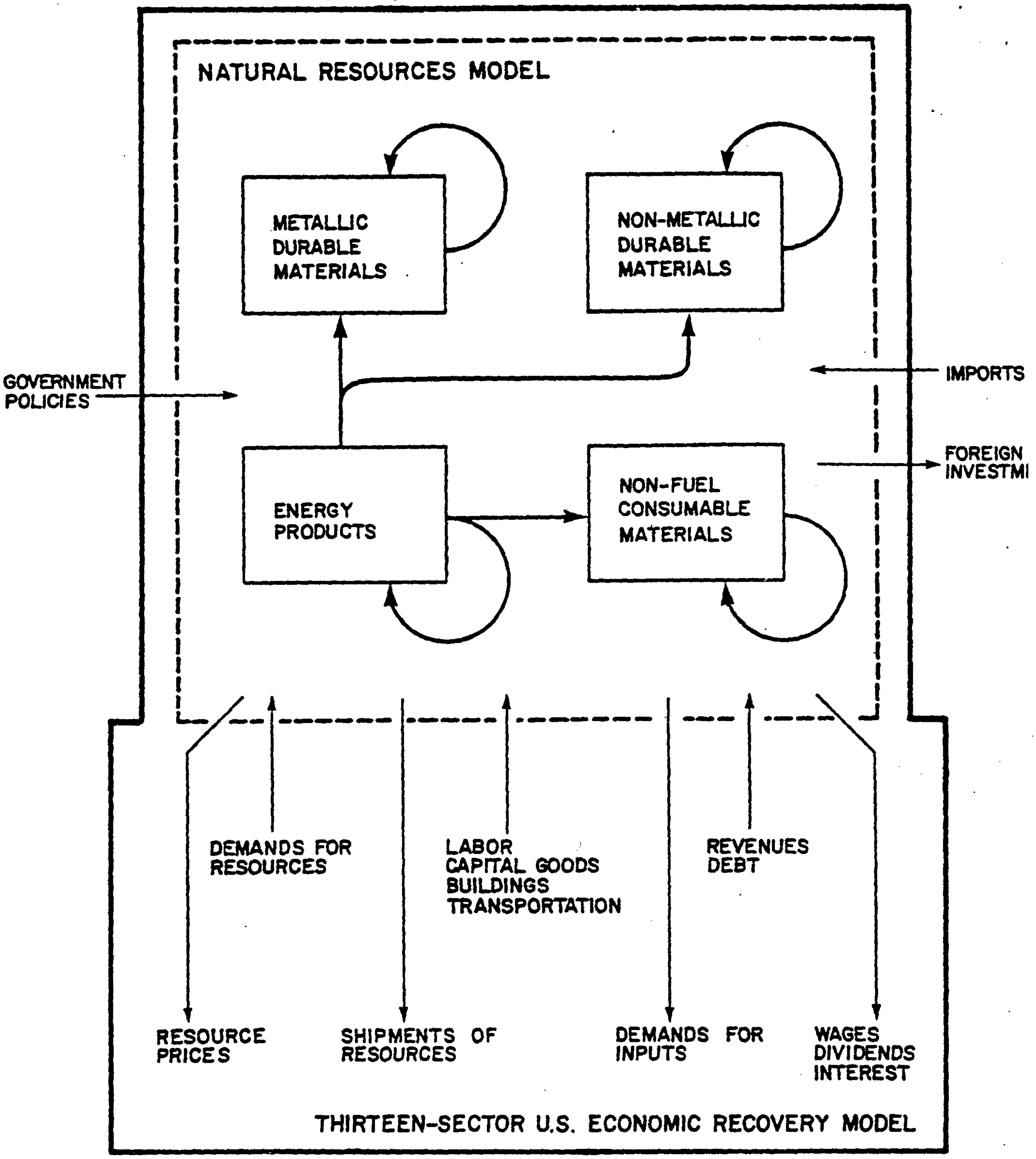
To summarize the developmental relationship between the two models, the natural resources model was intended to replace the original two natural resources sectors (called Durable Materials and Consumable Materials) in the multi-sectoral U.S. recovery model. The Phase I natural resources model was in fact imbedded in the overall U.S. model in May 1980, and

comprises four of that model's thirteen sectors. The final published version of the U.S. recovery model is thus configured. The natural resources model embedded in the U.S. economic recovery model is illustrated in Figure 4.6.

The subsequent Phase II natural resources model has the additional features enumerated above. This Phase II model also has achieved a higher degree of historical accuracy in the areas of prices, financial variables, and imports than either earlier versions of the natural resource model or the overall U.S. model, including more realistic cyclical behavior.

The Phase II natural resources model can be used in two configurations. First, it can operate as a stand-alone four sector model, as depicted in Figure 4.3. Basic resource demands (before consideration of price effects) and the availabilities of labor, capital goods, buildings, and transportation are exogenous inputs in this mode. Alternatively, the Phase II natural resources model can be operated embedded in the overall U.S. model, as depicted in Figure 4.6. In this second mode, basic demands and factor availabilities are determined endogenously by other sectors of the model. The embedded configuration captures the full dynamic input-output interplay between natural resources and the rest of the U.S. economy.

The stand-alone configuration has the advantages of relative ease and economy of use and requires proportionally smaller storage and execution region on a computer. Because this configuration is much less complex, it provides a clearer and more comprehendable view of problems particular to the four natural resource sectors (e.g., how their decision-making processes affect the rate of rebuilding, their abilities to finance rebuilding, how they are affected by stockpile operations and other government



THE NATURAL RESOURCES MODEL EMBEDDED IN
THE U.S. ECONOMIC RECOVERY MODEL

FIGURE 4.6

programs, their responses to import interruption). All of the simulations described in this report were produced with the four-sector, stand-alone version of the model.

D. Components of the Basic Sectoral Building Block

The basic building block of the natural resources model is not unlike the building block of the larger U.S. economic recovery model. Each sector has a structure that simulates finance, production, investment, deliveries, pricing, and trade. Further, a government policy sector interacts with the model in a user-specified fashion.

1. Finances

The financial status of each natural resource sector directly impacts capital investment decisions. Each sector determines a desired rate of expansion based on projected demand, expected profitability, a desired capacity margin for forecasting error, and intended replacement of deteriorating facilities. However, this expansion cannot occur when a sector's financial position is inadequate to support investment.

The financial strength of a sector is measured via accounting variables. Each sector has an associated balance sheet and income statement that is a simplification of standard double-entry bookkeeping. Cash, book value of capital, and value of inventory comprise each sector's assets, while debt and equity comprise the liabilities side of the balance sheet. These financial stocks, and the monetary flows which change them, are described in more detail below. All financial variables are measured in current dollars.

BALANCE SHEET VARIABLE	MONETARY FLOWS In	MONETARY FLOWS Out
Cash (CASH)	Revenues (REV) New Debt (NDEBT)	Debt Payments (DPAY) Interest Payments (IPAY) Cost of Production (COSTS) Cost of Government Stockpile Releases (COFGS) Cost of Imports (COFI) Tax Payments (TAX and ITAX) Dividends (DIV) Capital Investment (CINV)
Value of Inventory (VI)	Cost of Production (COSTS) Cost of Imports (COFI) Cost of Government Stockpile Releases (COFGS)	Cost of Sales (COFS) Cost of Inventory Losses (CIL)
Book Value of Capital (BVC)	Capital Investment (CINV)	Depreciation (DEP)
Equity (EQ)	Profits after Dividends (PAD)	
Debt (DEBT)	New Debt (NDEBT) Interest (INT)	Interest Payments (IPAY) Debt Payments (DPAY)

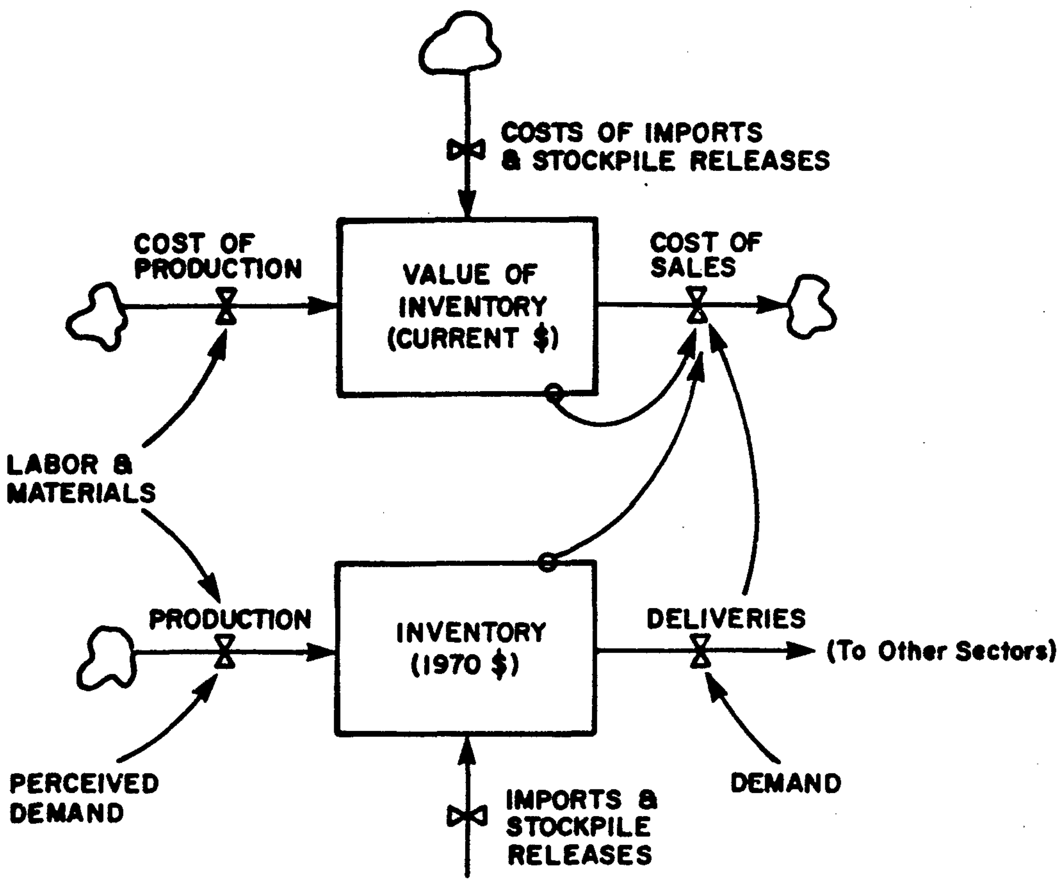
FIGURE 4.7

Figure 4.7 shows the balance sheet format used in the model financial structure. Each asset and liability is listed, along with those financial flows impacting the balance sheet.

As noted above, cash, book value of capital, and inventory value are the assets. Cash is increased by revenues and new debt, and decreased by any expenditure of the sector. Revenues are derived from shipments and price. The largest cash expenditures are the costs of production and imports. Payment of dividends, interest, and taxes, repayment of debt, and outlays for capital investment also deplete cash. Most of these expenditures are calculated in a straightforward fashion. Taxes are subdivided into an income tax based on gross profits, and property taxes based on book value of capital. Costs of production include labor and raw materials. Dividends are a percent of net profits, which varies depending on the adequacy of the sector's cash position (i.e., cash relative to cash requirements).

Book value capital represents the fixed assets of each sector. Capital investment (deliveries to a sector of capital goods or buildings) increases this stock, while simple straight-line depreciation depletes it. Achievement of a target rate of return on book value of capital is an important factor in pricing decisions.

Figure 4.8 shows the relationship between a sector's financial inventory and its physical inventory. The financial inventory is measured in current dollars. It reflects the average costs of production and imports for the goods in the physical inventory; i.e., inventory value is increased by costs of production and imports and decreased by costs of sales. The physical inventory is measured in constant 1970 dollars. As depicted in Figure 4.8, the financial inventory divided by the physical inventory



COST OF PRODUCTION = LABOR COSTS + MATERIAL COSTS

$$\textit{COST OF SALES} = \textit{DELIVERIES} \times \left(\frac{\textit{VALUE OF INVENTORY}}{\textit{INVENTORY}} \right)$$

RELATIONSHIP BETWEEN FINANCIAL & PHYSICAL INVENTORIES

FIGURE 4.8

equals the value per unit in the physical inventory. The cost of sales is simply the delivery rate times this value per unit.

Debt represents the loans outstanding to a sector, as well as accounts payable. Debt is increased by new debt acquisition and by the repayment of existing obligations. Furthermore, we assume that unpaid current interest obligations (the difference between interest and interest payments) is "capitalized" as additional debt. A sector may borrow for working capital and/or capital investment. Borrowing for working capital arises when financial resources on hand are insufficient to meet current expenses. Borrowing for capital investment is in part a financial policy decision to expand the production capacity of a sector. Debt availability is governed primarily by a sector's balance sheet equity. A maximum debt/equity ratio defines the ultimate limit, but borrowing is approached with increasing reluctance as this limit draws near. The formulation represents the inhibitions of both lenders and many borrowers themselves. On the other hand, a good record of past debt repayment increases the availability of new debt.

Balance-sheet equity is increased by retained earnings (profits after dividends). Profits after dividends are simply net profits less dividends paid; net profit are gross profits less income taxes. Gross profits are the difference between revenues and all sectoral expenses: cost of sales, interest, depreciation, property taxes, and inventory losses. Retained earnings contribute to internal cash flow, facilitating capital investment.

The financial structure and dynamics of the natural resources model are based on an "aggregate corporate" rather than "national accounts" approach. In the aggregate corporate approach, we treat each sector as an aggregation of individual business units, explicitly modeling all key

business decisions such as investment, borrowing, pricing, production, and employment. In the aftermath of a nuclear war, the financial environment will greatly influence the survival of industrial concerns and, ultimately, the path of economic recovery. Each surviving entity will most likely operate on an individual basis, struggling to maintain production and profitability in the face of immense shortages, low worker morale, a fragmented banking and market system. Under these conditions, we consider a market-oriented corporate approach to the behavior of each sector to be more robust, more accurate, and more useful for examining post-attack recovery than a national accounts approach which relies exclusively on pre-attack data streams.

2. Production

The "production function" in each natural resource sector is the group of equations which represent the use of the sector's inputs to produce its output. It must realistically specify the magnitude of production that can be supported by any given mix of inputs available to the sector. For example, the production function of the metals sector determines how much metal can be produced per year from the available quantities of labor, energy, and capital equipment.

To accurately simulate an economy under post-attack conditions requires degrees of realism and robustness beyond those of the production functions traditionally used in economic analysis. Specifically, the production function, in order to serve as a good simulator of the actual economy of the U.S., must achieve four "performance objectives":

a. Reasonable Behavior in Extreme Conditions. After a nuclear attack, any sector of the economy may find itself with a com-

pletely unbalanced mixture of inputs. The production function must realistically represent the consequences of great shortages of many inputs, with relative excesses of others. Typical econometric production functions are explicitly designed to work properly only within a narrow range of inputs close to their normal ratios. Although capable of accurately reproducing normal economic behavior, such functions often yield inconsistent results from severely imbalanced inputs. The production function of a post-attack recovery model must accurately track the consequences of sudden, violent changes in the absolute and relative magnitudes of all inputs.

b. Variable Criticality of Inputs. Some inputs are more critical than others. The production functions must accurately reflect the fact that shortages of some inputs may cripple production, while shortages of other inputs may have almost no immediate effect. For example, shortages of labor or machinery may immediately curtail the production of manufactured goods, but shortages of paint or packaging materials may have very little short-term impact on production rates.

c. Representation of Indirect Inputs. Many inputs which have little effect on immediate production may have delayed or indirect influences on the economic system. For example, a shortage of buildings may cause inefficiencies in production, but cannot stop production. The shortage of buildings may expose workers and machinery to weather, and thereby influence future production, as people become ill and machines rust and wear out faster than normal. Shortages of lubricants may have a similar indirect effect on production. Shortages of paints and coatings may have no effect on production, but may shorten the lifetime of the resulting products.

d. Representation of Changing Productivity. The production function must realistically take into account variations in the kind of inputs and their uses, as well as variations in their quantity. These qualitative changes can collectively be considered changes in a sector's production technology. They arise from the invention of new equipment and processes, from the depletion of easy-to-exploit natural resource deposits (and the resulting need to adopt more sophisticated production techniques), from the need to conserve increasingly scarce and expensive resources (through both reduced intensity of use and greater recycling), and from the need to conform with environmental controls and other government regulations.

The production function used in the natural resources model meets all of the above requirements. Although it may be used for any number of inputs, its basic mathematical structure is most clearly illustrated for

the simple case of two inputs. Figure 4.9 shows the basic form of the function with two inputs. At the top of the figure is an equation defining the output of a sector, as a function of these two input variables. First, the potential output from one input (input "B" in the figure) is considered. It is the output that could be achieved from the available quantity of input "B" if all other inputs were available in normal quantities. If there is a shortage of input "A", then only a fraction of the potential output from input "B" will be achieved. This fraction is defined as the "adequacy of input 'A'".

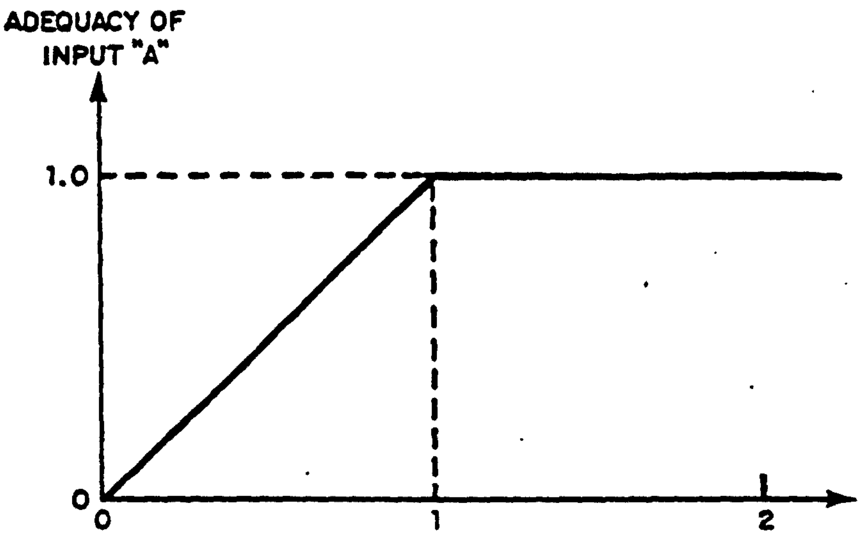
The key to the production function used in the model is the determination of the adequacy of input "A", illustrated in Figure 4.9. The adequacy is determined by the ratio of the potential output from the available amount of "A" (assuming unlimited quantities of "B"), divided by the potential output from the available amount of "B" (assuming unlimited quantities of "A"). If the ratio is less than one, then there is a relative shortage of "A". If the ratio is greater than one, then "B" is in short supply.

The shape of the "adequacy function" that relates the above ratio to the adequacy of "A" may vary, according to the importance of "A" and its role in production. The shape illustrated in Figure 4.9 is appropriate for inputs which are directly critical to production. Typical examples for most sectors are skilled labor, material stocks, and machinery which performs tasks impossible to do manually. If any one of these items is in short supply, it may limit production or stop it altogether. On the other hand, excesses of any one item will simply cause another critical input to become the limiting factor.

In fact, the exact shape of the adequacy function shown in Figure 4.9 makes the overall production function a simple minimum of the potential

$$\text{SECTOR OUTPUT} = \left(\begin{array}{l}\text{POTENTIAL OUTPUT}\\ \text{FROM INPUT "B"}\end{array}\right) * \left(\begin{array}{l}\text{ADEQUACY OF}\\ \text{INPUT "A"}\end{array}\right),$$

WHERE $\left(\begin{array}{l}\text{ADEQUACY OF}\\ \text{INPUT "A"}\end{array}\right)$ IS DETERMINED BY:



$$\text{RATIO}: \frac{\text{POTENTIAL OUTPUT FROM INPUT "A"}}{\text{POTENTIAL OUTPUT FROM INPUT "B"}}$$

Figure 4.9: MATHEMATICAL FORM OF THE PRODUCTION FUNCTION, WITH TWO INPUTS

productions from the individual inputs, each assuming an adequate supply of the others. For this reason, the function is called the "soft-minimum" production function. The reason for the qualifier "soft" is made clear in the next paragraph.

For some inputs in some sectors, the strict "minimum" shape of the adequacy function is inappropriate. For example, even the complete lack of some kinds of machinery may slow production, but not stop it (as is the case when the operation may be performed more slowly with hand tools). Figure 4.10 shows the shape of the adequacy function for such a nonessential, but helpful, input to production. Figure 4.11 shows an adequacy function which is even more general in shape. It illustrates the capability of the "soft-minimum" production function to represent variable elasticity inputs. The presence of such adequacy functions in a production function "softens" its characteristic of taking the strict minimum among the separate potential production rates; hence use of the term "soft-minimum" production function.

By cascading several such adequacy functions in the structure diagrammed in Figure 4.12, it is possible to generalize the soft-minimum production function to any number of inputs. The resulting production function meets all four of the requirements discussed earlier:

a. Reasonable Behavior in Extreme Conditions. With appropriate shapes of the component adequacy functions, the overall production function yields a reasonable output for any mix of inputs. Should any critical input be unavailable ("critical" implying its adequacy function has a value of zero for zero input), the resulting production output will be, correctly, zero. Excesses of any one component will not compensate for shortages of critical inputs, but for non-critical inputs, realistic tradeoffs may be represented.

b. Variable Criticality of Inputs. The shape of the adequacy function for each input specifies the criticality ("elasticity")

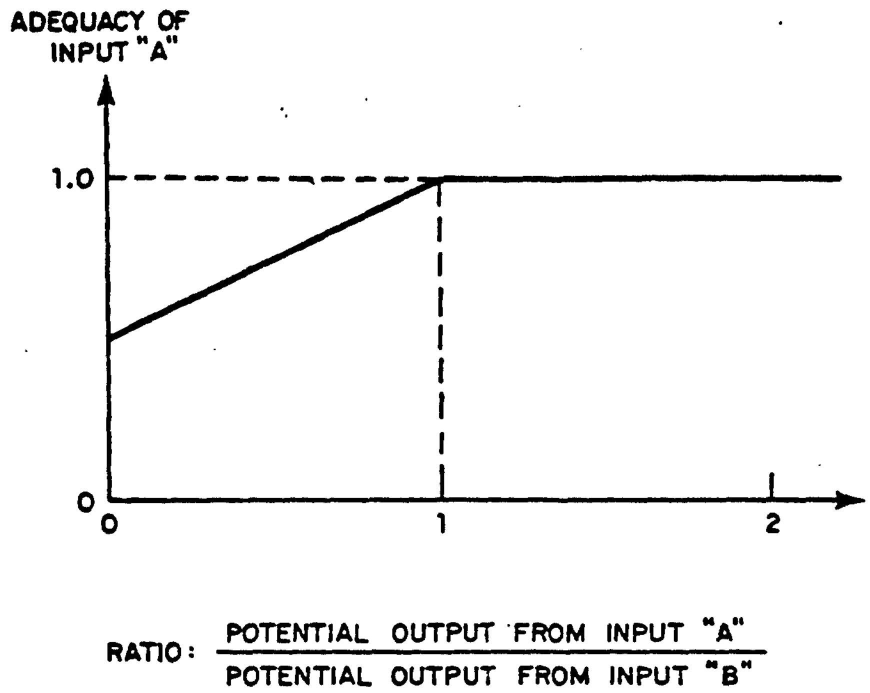


Figure 4.10: SHAPE OF THE "ADEQUACY FUNCTION" FOR A NON-CRITICAL INPUT

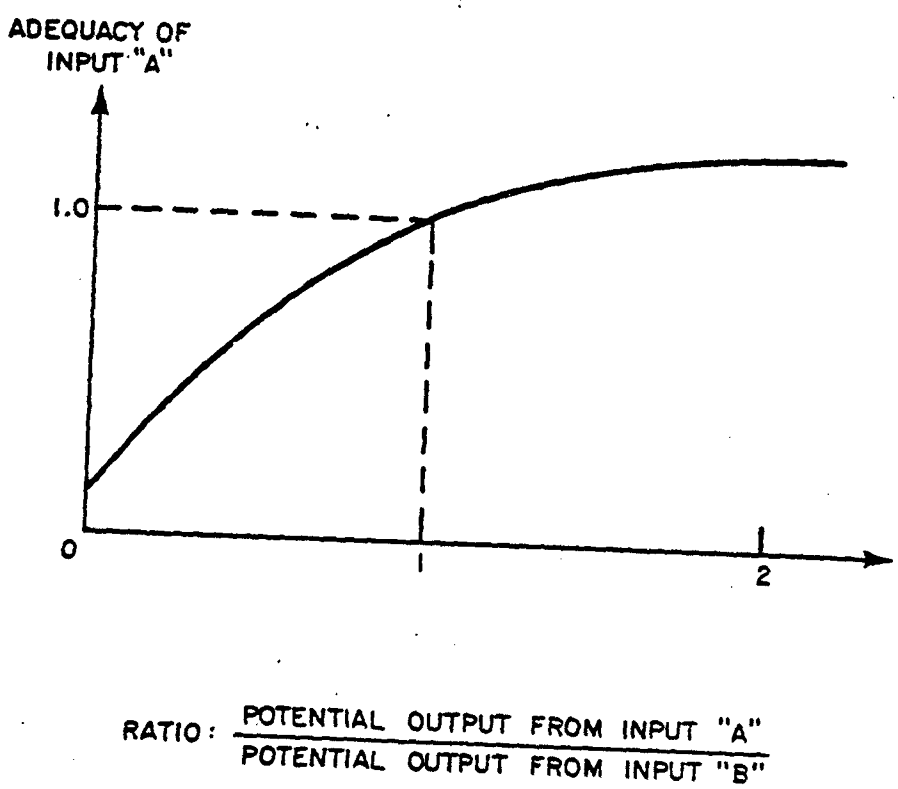


Figure 4.11: SHAPE OF THE ADEQUACY FUNCTION FOR SMOOTHLY-VARYING ELASTICITY

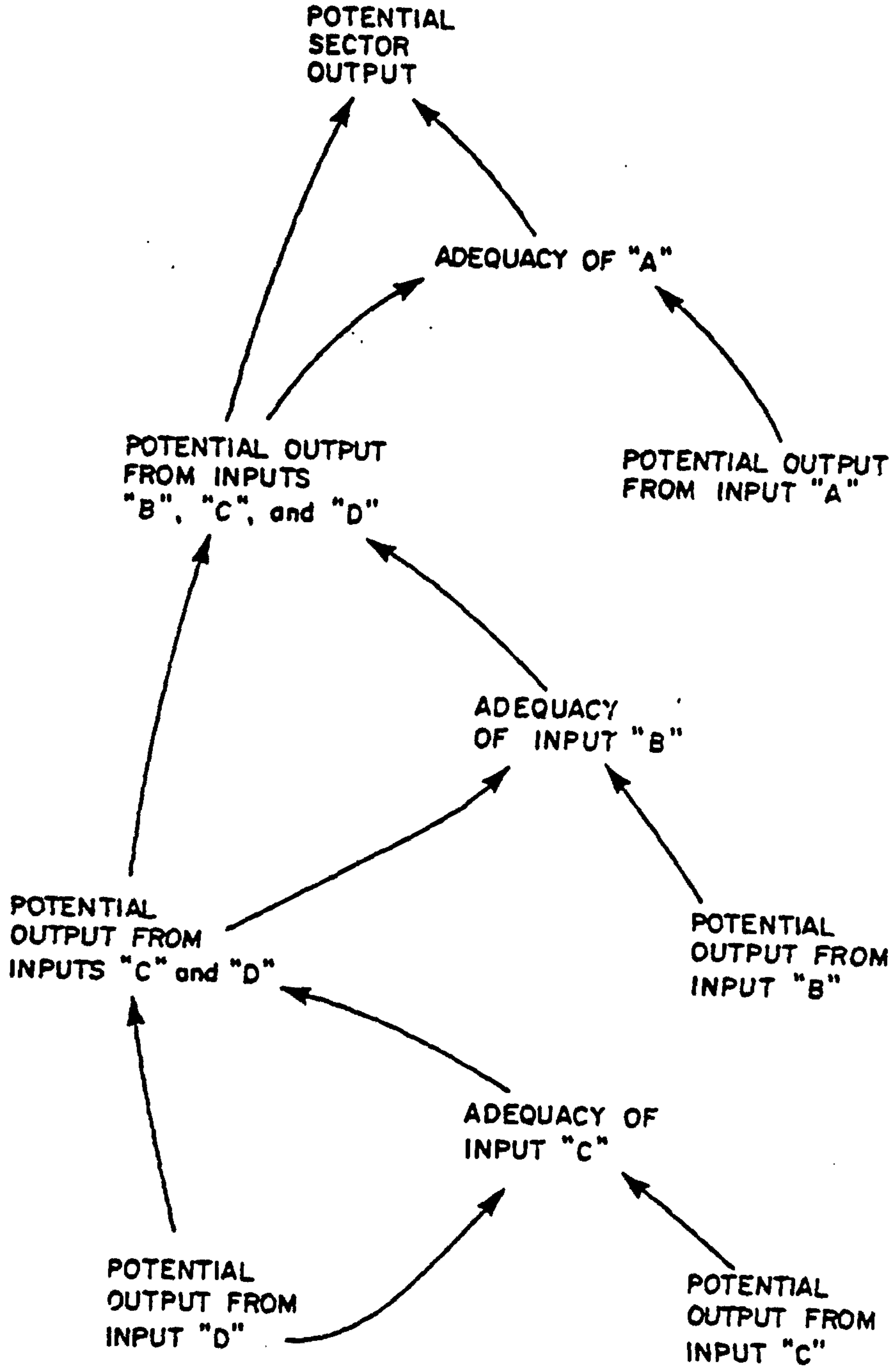


Figure 4.12: STRUCTURE OF THE PRODUCTION FUNCTION FOR MORE THAN TWO INPUTS

of the input. Because the shape of the adequacy function is defined by the user of the model, any degree of criticality may be specified. Different degrees of criticality may be specified for different conditions. Further variation in criticality may arise from the model's representation of technological change, as discussed below.

c. Representation of Indirect Inputs. Indirect inputs to production, such as buildings, may be given low or zero direct impact on production, by means of relatively flat adequacy functions. The other effects of indirect inputs, such as shortened life of capital equipment if shelter is inadequate, may be represented directly and naturally.

d. Representation of Changing Productivity. As will be shown below, the "soft-minimum" production function allows a natural, complete, and realistic representation of productivity change, which may affect production in several different ways.

Each natural resource sector of the model contains a production function of the general form described above. Figure 4.13 lists the actual production equation used in the model. Production is calculated as potential production from labor, modified by the adequacy of other critical inputs to production. In the natural resources model, these other critical inputs are limited to capital and energy.

As discussed earlier, the production function requires a calculation of the sectoral output possible with each input, assuming all the others were in adequate supply. In order to make this calculation, the sector building block contains variables representing the "productivity" of each input (that is, the amount of output possible per unit of input). These factor productivities are different for each sector and are variable over time. Inadequacies arise when the productivity of an input and the amount of that input available to a sector combine to indicate a production rate lower than desired production. Under these circumstances, sectoral output is constrained by the insufficiency of that critical input.

These same factor productivities govern the ordering dynamics of each sector. Desired production divided by the productivity of each input

```
P.K(T)=PPL.K(T)*AC.K(T)*AM.K(T)

     P     - DOMESTIC RESOURCE PRODUCTION (1970$/YEAR)
     PPL   - POTENTIAL PRODUCTION FROM LABOR
             (1970$/YEAR)
     AC    - ADEQUACY OF CAPITAL (DIMENSIONLESS)
     AM    - ADEQUACY OF ENERGY (DIMENSIONLESS)
```

FIGURE 4.13

determines how much of each input is needed. This requirement combines with financial considerations to determine requests by a sector for the input. Thus, factor productivities are a primary leverage point for affecting the behavior of the system through various Civil Defense policies.

The productivity of capital is defined as the amount of real output (1970$) per year obtained from each input of capital also measured in real units (1970$). The equation for productivity of capital is shown in Figure 4.14. The productivity of capital (CP) is computed as a "normal productivity" (CPN) times five different factors that cause productivity to deviate from its reference value. The normal productivity is defined as the value which would exist if all technological factors were at their 1965 levels (the simulations begin in 1965). The five modifying factors are effects of changes in basic industrial technology, resource depletion, environmental regulations, recycling, and price of energy. These effects on productivity are expressed by DYNAMO "TABLE" Functions (see Volume II) as multipliers which vary above or below 1.0. A value of 1.0 indicates no effect; a value less than 1.0 means that a factor is reducing productivity below its reference level.

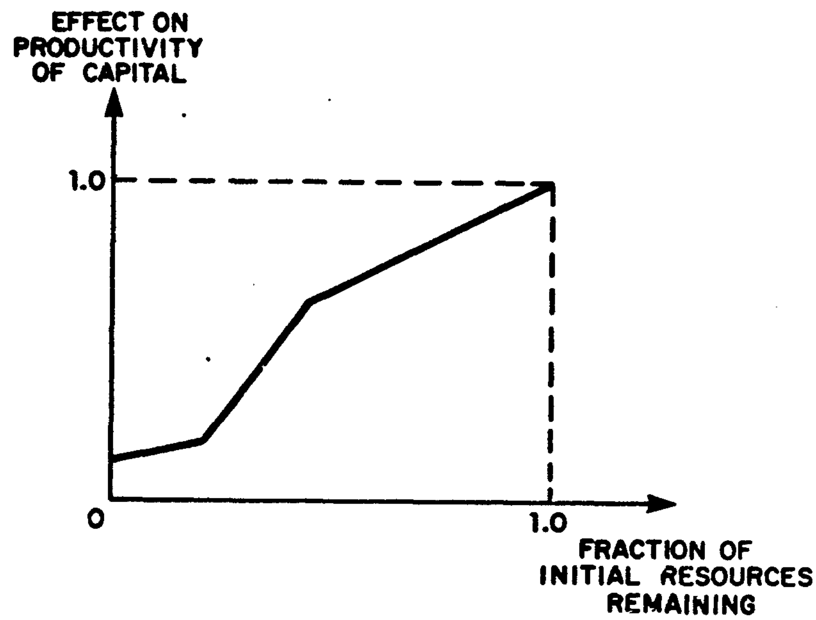
For example, the effect of resource depletion ERDPC is a TABLE function of the fraction of resources remaining. As resources are depleted via extraction, the fraction of resources remaining gets smaller. As shown in Figure 4.15 (using the metals sector as an example), this effect reduces the metals capital productivity, resulting in less output per unit capital then if resources were of higher grade, obtainable under less severe conditions, etc. With the lower productivity, the sector must order more capital to achieve a given production rate than if resources were less

depleted. The remainder of this section describes in detail the several effects on the productivities of sector inputs.

CP.K(T)=CPN(T)*ETCHPC.K(T)*ERDPC.K(T)*EERPC.K(T)*ERPC.K(T)*EP3PC.K(T)

CP	-	PRODUCTIVITY OF CAPITAL (1970$/1970$/YEAR)
CPN	-	NORMAL PRODUCTIVITY OF CAPITAL (1970$/1970$/YEAR)
ETCHPC	-	EFFECT OF TECHNOLOGY ON CAPITAL PRODUCTIVITY (DIMENSIONLESS)
ERDPC	-	EFFECT OF RESOURCE DEPLETION ON PRODUCTIVITY OF CAPITAL (DIMENSIONLESS)
EERPC	-	OVERALL EFFECT OF ENVIRONMENTAL REGULATIONS ON PRODUCTIVITY OF CAPITAL (DIMENSIONLESS)
ERPC	-	EFFECT OF RECYCLING ON PRODUCTIVITY OF CAPITAL (DIMENSIONLESS)
EP3PC	-	EFFECT OF ENERGY PRICE ON PRODUCTIVITY OF CAPITAL (DIMENSIONLESS)

FIGURE 4.14



EFFECT OF RESOURCE DEPLETION ON PRODUCTIVITY OF CAPITAL (Metals Sector)

FIGURE 4.15

a. <u>Basic Industrial Technology</u>. In many ways, the development of a modern economy is dominated by technological innovations and their implementation. For example, it is often said that the modernization of an economy is achieved by the substitution of capital for labor. But whether this is possible or not depends critically on the design, or technology, of the capital goods. A machine that allows one person to do the work formerly done by ten people does not contribute to the growth of the economy if twenty people are required to manufacture, maintain, and support the machine. Technology defines the processes available for economic activities such as manufacturing, and it also determines the amounts and kinds of raw materials required, the amount and kind of machinery required, and the number and skill level of people required. Technology, in other words, is the "recipe" of economic activity, specifying the inputs required to achieve a given output, and thereby determining the normal cost of that output.

The model, therefore, represents industrial technology as one of the determinants of the efficiencies of each input to the production function. The productivity of each factor of production is represented in the model as a function of the level of technology implemented in the sector. "Technology" itself is measured on an arbitrary scale from zero to three, where 1.0 represents, by definition, the average of level of technology in each sector in 1965. The use of a single variable to represent the implemented level of basic industrial technology in each sector allows the model to realistically coordinate changes in efficiencies of each input, as new technology is absorbed.

The model assumes that the implementation of technology is tied to the stock of capital equipment. Associated with each stock of capital equip-

ment in each sector is a "stock" of implemented technology. Each unit of capital added to the capital stock causes a number to "technology units" to be added to the corresponding technology stock. The number of technology units added is determined by the state-of-the-art technology available for implementation at the time the capital is acquired.

Whenever a unit of capital equipment is destroyed or scrapped, the corresponding technology stock is decreased by a number of technology units equal to the average level of technology implemented in the capital stock. The model might be enhanced by introducing a "vintage" representation of capital stocks, in which case the oldest, and less than average technology, equipment could be scrapped. The present formulation, however, is simpler. Furthermore, the assumption that lost capital is of average technology is probably more accurate for the case of capital lost in a nuclear attack.

b. Resource Depletion. Certain critical issues in economic growth affect primarily the initial stages of production chains. Resource depletion is one of those issues. Scarcity due to the depletion of resource reserves, seen already in domestic crude petroleum output and in iron ore, generally causes two consequences. First, the financial dynamics of the affected extraction sectors change. Resource depletion implies that domestic supply is still available, but at higher cost (and often less-profitability) to the sector. More capital goods, labor, and energy are required to obtain the resources. Per-unit production costs grow rapidly as geological conditions and resource concentrations (e.g., ore grades) decline, mines and wells are dug deeper or in more remote and forbidding locations (e.g., the Alaskan North Slope), and much new exploration is required. Second, because domestic production becomes less "economic," imports increase to the extent they are available.

These two consequences are intertwined. As resources are depleted, investment and production costs rise. Producers respond by raising prices. Imports become increasingly attractive as cheap domestic supply is exhausted.

The model formulation of resource depletion uses "proven" and "probable" reserves as a measure of total domestic resources remaining for extraction in the metals and energy sectors.[6] The fraction of total sector production that actually extracts resources (recall that the sectors include processing and basic fabrication, too) and the sectoral production rate in tons determine the annual extraction rate which depletes resources. As resources are depleted compared to their amounts in 1965, capital productivity goes down (see Figure 4.15). Thus, to maintain supply from domestic sources, more and more capital investment is required.

c. Environmental Regulation. The impact of environmental regulation on U.S. industry has been increasing steadily since the early 1970s. The emergence of pollution as a critical domestic problem has resulted in major revision in Federal regulations concerning production and transportation. The natural resource sectors of the economy have been especially affected by these regulations.

Generally, pollution control regulations are implemented at the expense of productivity. The natural resources model includes two different impacts of environmental regulation. Both affect the productivity of capital in each respective natural resource sector. Capital can become less productive either "operationally" or "intrinsically." Operationally, capital becomes less productive as its mode of use is changed to comply with new environmental standards (for example, oil tankers not flushing their ballast at sea but, rather, cleaning tanks in port where the oily

water can be taken away; this increases port time and reduces voyages per year of the ship). Strictly speaking, this effect represents the less efficient use of capital due to environmental regulations.

The other aspect of environmental regulations is to require new types of capital equipment, with features specifically intended to reduce pollution (for example, requiring oil tankers with segregated ballast systems). More capital is required per unit of production than before. Some of that investment does not, per se, contribute to output (for example, the retrofitting of pollution control devices on existing facilities and equipment). Hence, the intrinsic productivity of capital has declined. In the natural resources model, each new piece of capital has an associated environmental technology, as specified by environmental standards. Since environmental standards are assumed to become more vigorous with time, the average environmental technology of a sector is assumed to increase. The higher the implemented environmental technology in a sector, the lower the intrinsic productivity of capital in that sector. Through both this effect and the effect on operating efficiency mentioned above, the model represents how environmental regulations have caused the natural resource sectors to undertake higher capital investment.

Both the intrinsic and operational effects of environmental regulations on productivity can be manipulated as policy levers. A relaxation of environmental standards to stimulate production in the short-term is easily simulated by varying the inputs.

d. Recycling. A significant amount of metals processing is a result of recycling. Recycling occurs in two fashions. The first is the recycling of new scrap; scrap produced at a production site during metal processing is immediately re-introduced into the production process. This

new scrap is necessarily created in metals production and customarily recycled. This form of recycling is assumed to be price-insensitive.

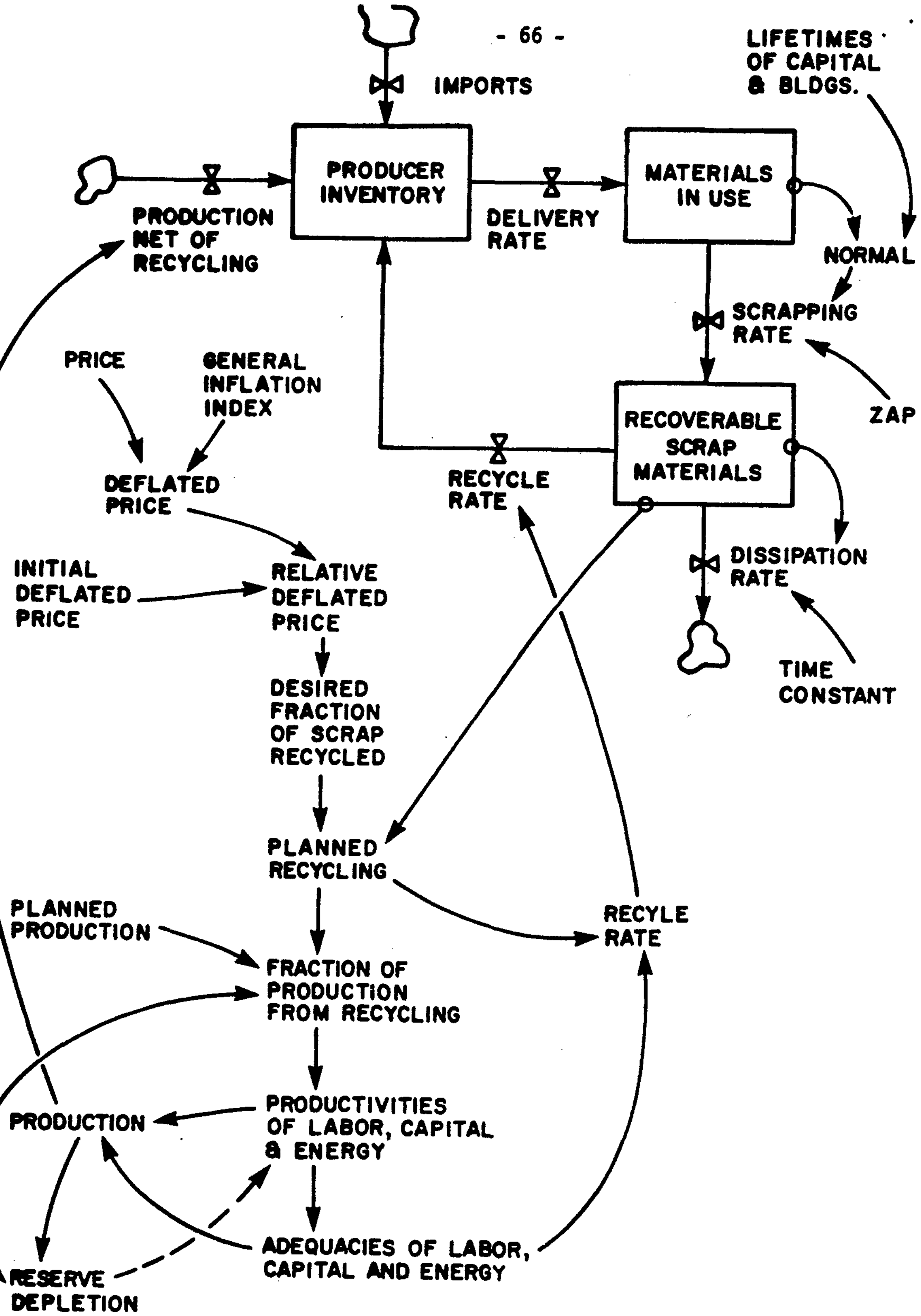
The second form of recycling involves old scrap, i.e., the collection of material to recycle at a profit. The amount of this recycling is price-dependent, resulting in increased recycling with increased real price. If price (in real terms) increases, it becomes profitable enough to recycle scrap metal that would otherwise deteriorate.

Figure 4.16 shows the dynamics of recycling in the natural resources model. The model formulation involves a measure of desired recycling (as indicated by real price), which combines with the availability of scrap to give a rate of recycling. Scrap is generated from the stock of "materials in use".

In the model, desired recycling is a function of relative real price, i.e., the current deflated price divided by the deflated price in 1965 as a reference point. The idea is that the price of a material has to rise faster than the general inflation rate to make recycling more profitable. Otherwise, the costs of recycling keep it from being an economically attractive proposition. As relative real price rises, recycling becomes more and more profitable and increases significantly. This represents the recycling of old scrap. However, if relative real price drops, recycling does not decline past a certain amount, representing the new scrap recycling that is price-insensitive.

Recycling makes both capital and energy more productive. The higher the percentage of production accomplished via recycling, the less energy and capital a sector needs.

e. Energy Price. The final effect on productivity results from the real relative price of energy. This final effect is a conservation



DYNAMICS OF RECYCLING AND RESOURCE DEPLETION

FIGURE 4.16

effect. As the real price energy rises, the economy takes initial measures to reduce consumption. These include such policies as lowering thermostats, carpooling, etc. These internal conservation mechanisms are, in effect, an increase in energy productivity in response to an increase in real energy price. After a certain point, however, capital investment is required to achieve energy savings: fuel-efficient furnaces, insulation in factories, fuel-efficient extraction equipment, and the like. Thus, increases in real energy price depress productivity of capital, but in a way that presumably is justified by a more-than-offsetting saving of energy.

3. Capital Investment

Each sector in the natural resources model has a stock of capital equipment used for the production of that sector's output. Machinery, pipes, and other fabricated metal products, engines, electrical and electronic equipment, and vehicles are included in this capital stock.[7]

The physical mechanisms that maintain and expand this capital stock are represented through capacity planning and capital investment equations. In each sector, a desired capital stock is calculated dependent upon several factors. Obsolescence of existing capital provides pressure to replace worn-out stock. Expected demand for a sector's output provides a benchmark to measure how suitable the existing amount of a sector's capital will be in meeting the expected demand: any discrepancy produces pressure to expand. Finally, considerations of expected profitability, the relative attractiveness of overseas investment, and desired capacity margin modify the capital requests. Higher expected profits from new capital tend to increase capital requests.

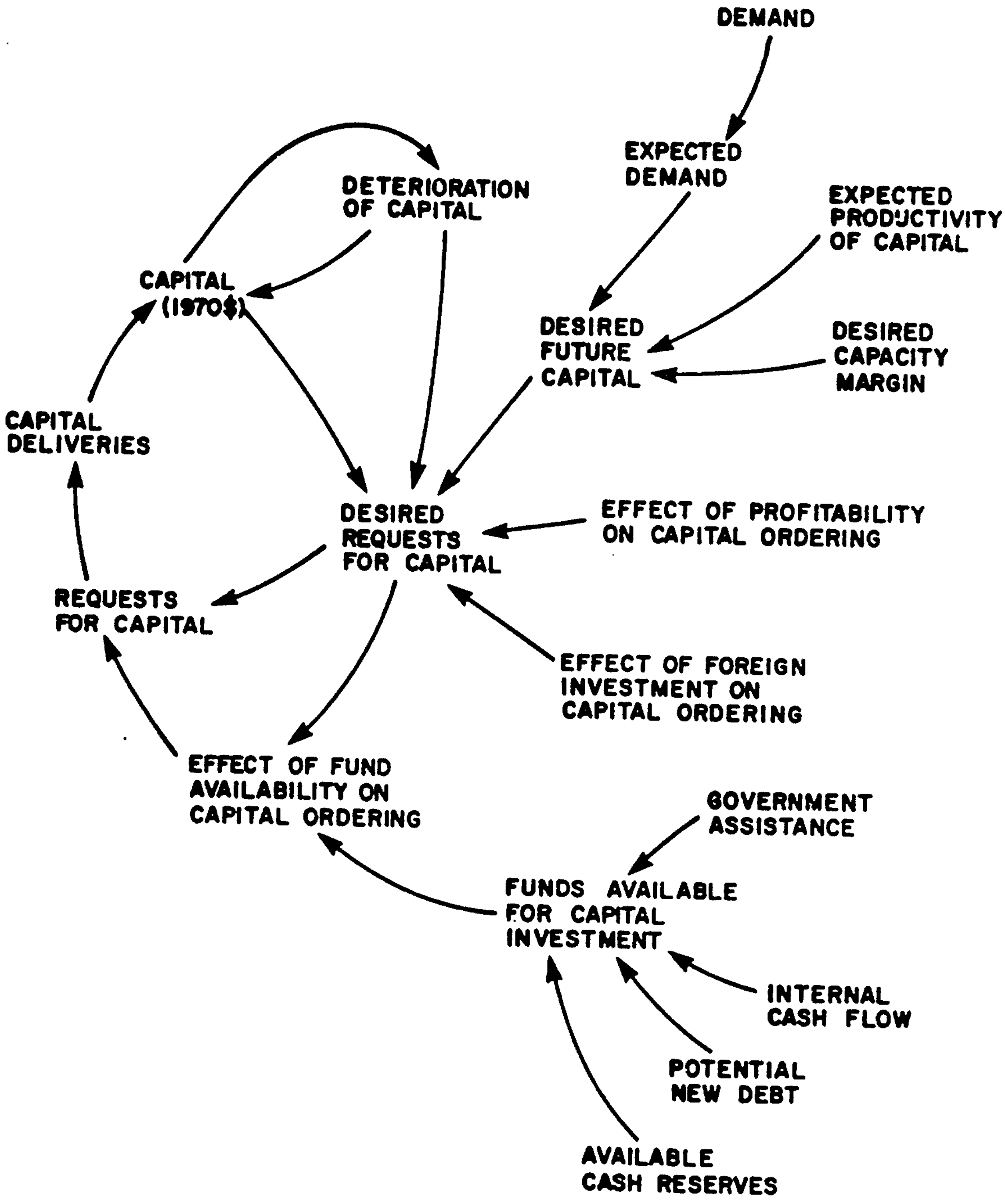
In this manner, the additional capital desired by each sector is derived. The physical requests to the capital manufacturing sector, however, are constrained by the financial portion of the model. A sector must be able to pay for new capital (through current cash flow, accumulated cash reserves, acquisition of new debt) before orders are placed.

Figure 4.17 depicts the capital ordering scheme used in the model. The desired future stock of capital is determined from expected future demand, expected productivity of capital, and the desired capacity margin above what is required to satisfy expected demand. Both demand and expected productivity are extrapolated from recent values over a planning horizon (generally five years into the future). Thus, desired future capital stock is compared with the present stock to determine necessary expansion. Replacement of worn-out capital is added in. The result is a preliminary value for desired requests for capital.

This preliminary value is modified in two fashions. First, expected profitability (as defined by return on investment, or ROI) modulates capital requests. High expected ROI drives up capital requests, while low expected ROI decreases them. Further, domestic ROI compared with the ROI available overseas impacts a sector's investment decisions. If investing outside the U.S. appears to be more profitable to a sector, capital ordering for U.S. production is reduced.

A second component of capital investment in each sector is the stock of buildings and structures. The aquisition of buildings occurs when sectors order new construction. The logic and constraints of ordering new construction are similar to that for the ordering of capital equipment as described above.

Structures, unlike capital equipment, have no direct impact on pro-



CAPITAL ORDERING DYNAMICS

FIGURE 4.17

duction. However, structures exert their influence in several indirect ways. First, structures are required for housing capital equipment. An inadequate supply of these structures will result in more-rapidly-than-planned deterioration of machinery and equipment. Second, structures are used to store inventories of goods and materials. Inadequate facilities will cause more rapid inventory losses. Finally, structures, such as office buildings, stores, and plants, provide shelter for laborers. An inadequate supply of these facilities is likely to depress the productivity of labor, as a result of discomfort and interference from weather.

Therefore, although the output of the construction and building sector is not a direct input to the production of goods and services, structures serve a critical function in protecting labor, capital, and the output of other sectors.

4. Resource Allocation

Under ideal conditions of normal profitability and availability of resources, United States industry usually strives to meet the demands placed on it by consumers and by other components of industry. Under such conditions, orders (after some delay) are transformed into shipments. Under simulated conditions of normal availability of goods, the model behaves in a similar way.

However, under some conditions (especially post-nuclear attack), demand may exceed supply for many products. In an "ideal" economy it might be argued that quick adjustments in price would cause supply and demand to equilibrate, but in practice prices often adjust too slowly to avoid periods of excess demand. Therefore, individual corporations and entire industries often find themselves in a position of having to allocate their

output to their customers according to some scheme that takes into account the relative sizes and priorities of the customers. In times of war or emergency, such allocation and rationing schemes may become the responsibility of government.

To realistically capture the allocation of scarce resources, the natural resources model contains a robust representation of the prioritized distribution of the output of each sector. The logic of this allocation scheme meets the following important criteria:

a. The deliveries to the receiving sectors sum to the amount delivered from the supplying sector, under all conditions.

b. All deliveries are positive.

c. No sector receives more than it orders.

d. Under conditions of adequate supply, each sector receives the quantity it orders.

e. Under conditions of shortages, uniquely low-priority sectors absorb most of the shortfall; uniquely high-priority sectors receive as much of their demands as possible, consistent with constraints above.

The equations controlling resource allocation are contained in the "SHARE" macro of the model. A macro is a programming feature of the DYNAMO language, which allows a block of equations to be reused multiple times (e.g., for each sector and input to production).

Each sector of the model is assigned a normal priority number for each input it orders. These may be changed by model users to experiment with alternative allocation policies. Priority numbers vary from 0 to 1, where 0 represents minimum priority, and 1 represents maximum priority. The essential logic of the SHARE macro of the model is as follows. Each sector receives the amount it orders of a given commodity, minus a fraction of the

production shortfall of that commodity. The fraction of the shortfall absorbed by any sector is determined by the relative demands of the receiving sectors, and by their relative priorities.

The shortfalls are defined to be positive when demand exceeds production; to be zero (rather than negative) when production capacity exceeds demand. In the latter case, therefore, each sector has some (irrelevant) share of a zero shortfall deducted from its desired deliveries, so that each sector receives what it asks for, and the excess supply remains with the supplying sector.

The mathematics of the SHARE macro are easiest to visualize in the case of two sectors competing for one product. Let D1 and D2 represent the demands of two sectors for the output of some supplying sector. Similarly, let PR1 and PR2 be the corresponding priorities. If these is a shortfall SF of the product, then the first sector will receive

$$R1 = D1 - SF * (D1/PR1) / ((D1/PR1)+(D2/PR2)).$$

Similarly, the second sector will receive

$$R2 = D2 - SF * (D2/PR2) / ((D1/PR1)+(D2/PR2)).$$

It is straightforward to confirm mathematically that these equations meet the requirements listed above, except for the second requirement. In order to avoid negative deliveries under all conditions, the priorities must sometimes be adjusted to avoid giving a large fraction of a large shortfall to a small, low-priority sector. The SHARE logic of the model, therefore, tests for such conditions and increases the priority of the

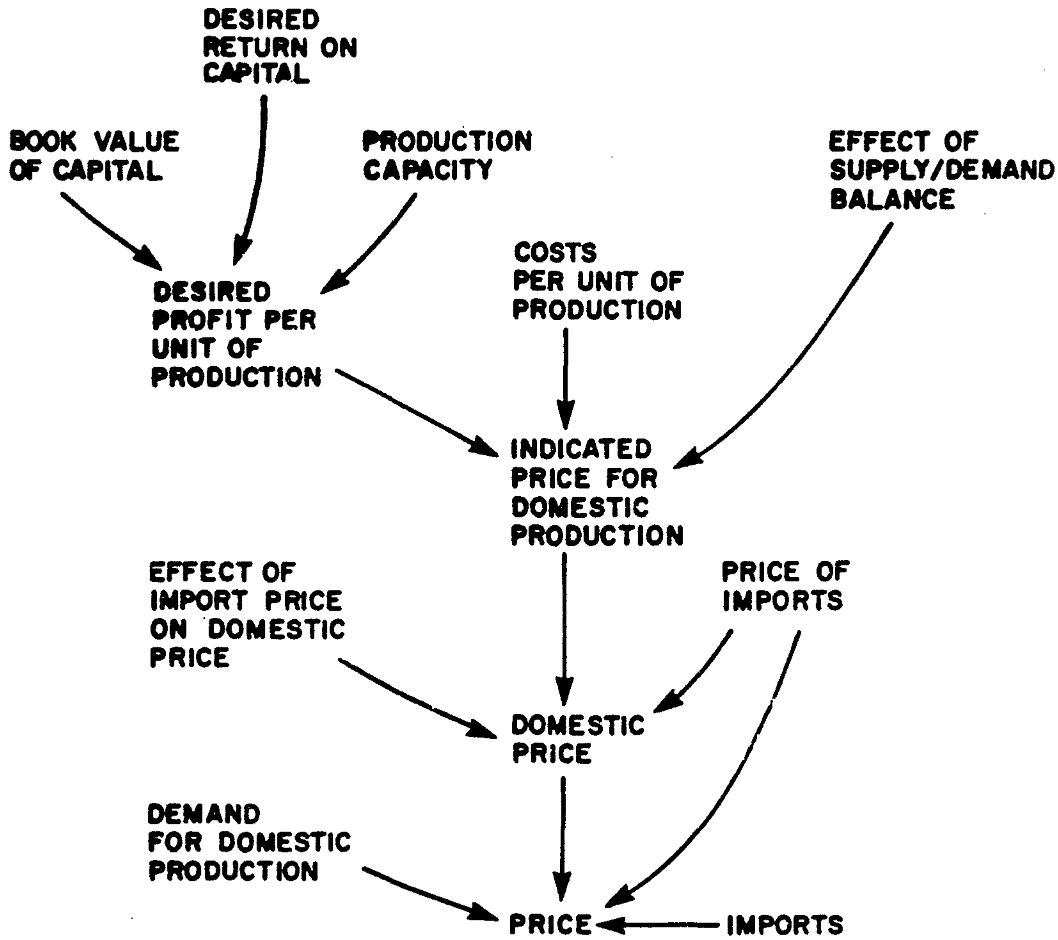
small, low priority sector high enough to avoid negative deliveries. By definition, such adjusted priorities occur only for sectors whose total demand is small compared to the shortfall. Therefore, the effect on the normally high-priority sectors is negligible, and the second requirement is satisfied without significantly compromising any of the other requirements.

Because the SHARE logic behaves like a normal market economy as long as there is no shortfall, the model can smoothly and logically represent the transition from adequacy to severe shortages without special adjustments or inputs. Different combinations of priorities may be tested to evaluate the general strategy of resource allocation required to maximize recovery.

5. Prices

Prices are set by each sector based on a combination of expected costs per unit of output, desired return on capital, the market forces of supply and demand, and the import price. The logic by which prices are calculated is shown in Figure 4.18. Prices determine revenues and costs to each sector, influencing indirectly all balance sheet and income statement variables.

In the natural resources model, prices also affect the mix of inputs ordered by the producing sectors. As discussed above, there are several paths through which these effects operate. Price affects the recycling of durable materials; recycling changes the productivities of labor, capital, and energy in durable materials production, and hence the mix of inputs. The price of energy affects energy consumption and induces energy-saving capital investment. Relative prices affect how much of required raw materials come from domestic production versus imports. Finally, in the



CALCULATION OF RESOURCE PRICE

FIGURE 4.18

stand-alone version of the natural resources model, price affects the basic exogenous demands for resources from other sectors of the U.S. economy (see Section C above). This is a proxy for the conservation decisions represented explicitly for energy inside the four natural resource sectors.

The overall price of a resource consumed in the U.S. economy is calculated as a weighted average of domestic price and import price. Import price is exogenous to the model. Domestic price fundamentally is determined on a cost plus desired profit basis, although as described below other factors enter in.

The price calculation starts with production costs. Added to per-unit production costs is a desired per-unit profit on each item produced. This profit is based on a target after tax return on the book value of capital in each sector. The market effects alter price according to the perceived supply/demand balance. If a resource is in short supply, price is increased. To a lesser extent price is decreased in an environment of excess supply. This reflects the assumption that producers are averse to selling below cost at a loss, while on the upside it is more a case of what the market will bear.

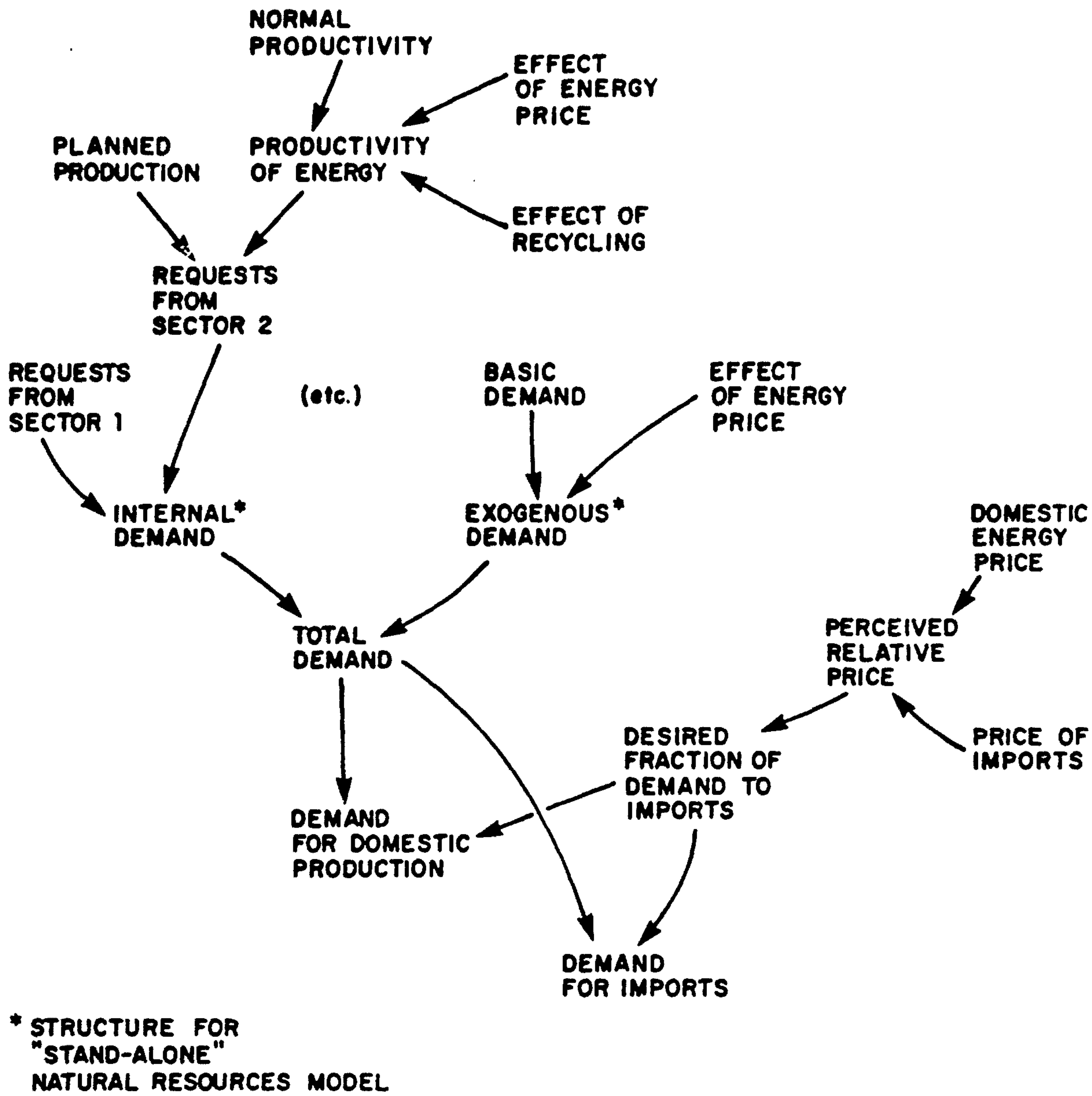
The interplay between price and demand also operates through the productivity equations. High energy prices, as discussed earlier, tend to increase the productivity of energy in each sector as corporations begin conservation measures. As energy productivity increases, each sector obtains more output per unit energy consumed. Thus energy demand is reduced and, via the supply/demand balance effect, price is also depressed.

6. Foreign Trade

Foreign trade has tremendous implications for the U.S. economy, both in peacetime and time of war. The critical dependence of the United States economy on foreign supplies of petroleum first became a national issue with the 1973 Arab oil embargo. Since then, demand for petroleum products has increased, making the U.S. even more dependent on imports. As a result, the political instability of the Middle-East oil-producing region and the continuing possibility of reduced import availability pose a serious threat. In 1978, the U.S. imported about 25% of its total energy consumption. The Arab OPEC nations (Algeria, Iran, Iraq, Kuwait, Libya, Qatar, Saudi Arabia, and the United Arab Emirates) accounted for nearly half of those imports.[8]

U.S. import dependence is not limited to petroleum. Chromium, a strategic metal with no substitutes, critical to the aerospace and armaments industries, is not available domestically. Chromium is found primarily in southern Africa, with 99% of known reserves located in two politically-sensitive countries: Zimbabwe and the Republic of South Africa. Other major chromium producers include the Soviet Union and Turkey. Worse, chromium is not a special case. Columbium (with applications to the nuclear and aerospace industries), mica (critical to electrical circuitry), strontium (pyrotechnics applications), and manganese (critical to alloying steel) are just some of the strategic metals the U.S. imports.[9]

Imports in the natural resource model are a function of relative price and availability, and of the sufficiency of domestic production to meet demand. The calculation of demand for a resource and imports is shown in Figure 4.19. Desired imports are a function of relative price of domestic output versus imported materials. A significantly lower import price means



CALCULATION OF RESOURCE DEMAND
(Energy)

FIGURE 4.19

that imports are a better deal for consumers. Under such circumstances, desired imports increase. If domestic production cannot meet the remaining demand, additional imports are requested to bridge the gap. Of course, if import availability is restricted, imports may be less than the desired amounts.

7. Government

The natural resources model can represent the government in a variety of roles as the central planner in the recovery process. Many specific parameters, or policy levers, are incorporated into the model to allow the convenient simulation of possible avenues of government intervention and initiative. Government is represented at a general level, via the impacts of Federal economic policies and regulations, and at a Civil Defense level, via such programs as stockpiling or resource conservation.

General economic policies are represented in an "exogenous" fashion; they are user-defined inputs to the model. An example of a government policy discussed earlier is the effect of environmental regulations. Other areas where government policies can be tested include: taxation, accelerated depreciation, interest rates, debt repayment and interest deferral, direct financial assistance to sectors (via subsidies or "soft" loans), dividend restrictions, wage and price control, and limitations on foreign trade. Government guaranteeing of loans, thereby allowing sectors to borrow beyond their normal debt/equity limits, can also be examined.

In a wartime environment, the primary manner by which the government can influence the flows of physical goods in the U.S. economy is by determining each sector's priorities for receiving scarce commodities. The resource allocation logic used in the model attaches a priority to the

request of each sector for the output of another sector. This aspect of the model alone provides a powerful tool to strategic planners. Simulations in which the attack scenario remains constant but the sector priorities differ can be compared, optimizing economic recovery relative to which sectors of the economy receive preference in obtaining the output of other sectors. Since the model is capable of handling any combination of priorities, rapid analyses of central planning strategies are feasible.

Civil Defense policies relating specifically to natural resources also can be examined using the model. Raw material stockpiling programs (stockpile objectives and the ground rules for aquisition and release) are included. The effects of a government shelter-building programs on the natural resource industries can be simulated by varying damage to the sectors in terms of manpower, capital goods, resource stockpiles, and reserves, and by synchronized increases in pre-attack resource demands (i.e., the materials required for shelter construction). Emergency resource conservation and recycling programs can be tested. In addition, pre-war conservation efforts and incentives to stimulate domestic natural resource development, and their effects on post-attack recovery, can be investigated.

Stockpiling is represented simply but comprehensively in the model. Production of any of the sectors can be stockpiled. Over the historical period, only the metals stockpile contains material. Stockpiles are built based on desired receipts of stockpile material, which is a policy input to the model. Stockpile releases are governed by either user-defined inputs or by each sector's supply/demand balance.

If the government desires to build stockpiles, requests for materials for this purpose become part of the overall demand on the natural resource

sectors. These requests have an associated priority and compete with requests from the rest of the economy for available resources. Thus, satisfying the demand for building or rebuilding government stockpiles is not guaranteed. The market impact of a government stockpile program will depend on its magnitude, its priority, and the prevailing supply/demand balance.

Different stockpile release policies can be examined using the model. Varying the assumed relationship between the rate of stockpile release, and the supply/demand balance for each resource, simulates heightened or reduced sensitivity of the government to fulfilling industry's requests for scarce materials. Also, varying the perception time associated with the government's calculation of each sector's supply/demand balance can represent rapid or cautious release policies. Other aspects of the model's stockpiling formulation include the ability to destroy or contaminate stockpiles as part of an attack scenario, and for stockpiles to deteriorate from inadequate building protection. The model also can represent the pre-attack "hardening" of resource stockpiles, so that they suffer less destruction than the resource sectors as a whole.

The model can thus simulate shifts in policy that precede or follow an attack. Allocation and rationing of scarce resources may suddenly become active, or be phased-in on a gradual basis. Wage and price controls may be introduced. Foreign trade may be reduced or eliminated. Any of these policies may be simulated alone, or in concert with one another.

8. Representation of Damage

The model represents damage from a nuclear attack (or other emergency) through a combination of three mechanisms: a) the sudden reduction of stock variables; b) the sudden transfer of stocks into some different condition; and c) shifts in time-based inputs to the model. It should be emphasized that the fundamental "attack" inputs to the model are physical, economic, and social damage, not bombs, per se. Therefore, the translation of weapons "laydowns" into specific damage is the responsibility of the user, outside the model.

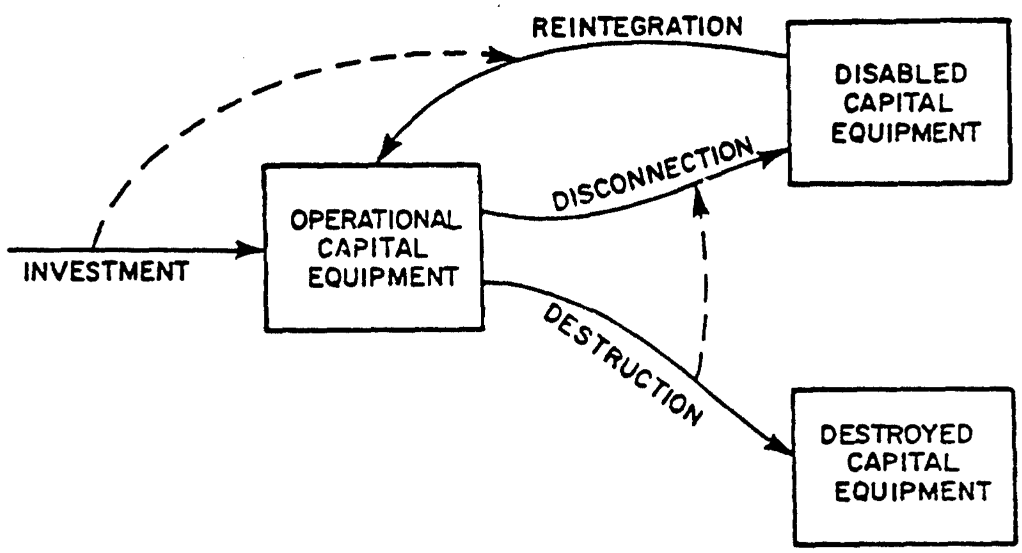
The first means of representing damage in the model is the sudden drawdown of stock variables at a time or times specified by the user. The equation for each important stock variable includes a special, depleting flow which is normally zero. At the time of an attack the flow is "pulsed" (takes on a large value for only one increment of time) to suddenly subtract, or "zap" as it is called in the model, the specified fraction of the contents of the stock. The user can thereby cause at any time in a simulation the "destruction" of any fraction of capital goods, buildings, people, inventories, resource stockpiles and reserves, balance-sheet variables, and expectations. Expectations include perceived and forecasted demands, availability of imports, etc. The magnitude of all the damage effects may be varied sector by sector and over time to simulate uneven damage and multiple attacks.

In addition to the sudden destruction of stocks, the model allows the transfer of some stocks into special categories. Capital equipment may be transferred into two special categories at the time of an attack. First, when capital equipment (and buildings) are destroyed, a proportional amount

of the stock of materials in use (see Figure 4.16) is transferred into the category of scrap. In the post-attack environment, this rubble may serve as a source of recycled durable materials, temporarily augmenting primary production.

A second kind of transfer of capital equipment allows the model to realistically represent the damage of key links in interconnected systems. For example, the destruction of a few control points may render inoperative 80% of an electric power grid, even if only 10% of the physical system was destroyed. The model represents this effect by shifting some surviving capital of each sector into a "disconnected" category, which is defined as undamaged equipment that can make no contribution to current production. Each unit of destroyed capital, at the moment of its destruction, carries with it a specified quantity of undestroyed capital into the disconnected category. Post-attack, the model assumes that any capital investment made is first applied to repairing destroyed bottlenecks; therefore, each new unit of capital constructed restores, at no additional cost, the specified quantity of disconnected capital to the operative condition. Figure 4.20 illustrates these coordinated flows of capital.

The third way of representing damage involves altering time-phased post-attack inputs. These time-phased inputs, in general, define aspects of the economic environment which are not calculated inside the model. For the four-sector, stand-alone natural resources model, such variables include: post-attack labor and capital goods costs and overall inflation; reductions in the demand for natural resources from "other" (i.e., non-resource) sectors; and availability of inputs to production. Inputs to production include labor, capital goods, buildings, and transportation. At attack time, the availability of any of these inputs can be reduced, to



KEY:

——➤ "FLOW" OF EQUIPMENT FROM ONE CONDITION TO ANOTHER

----➤ CAUSAL IMPACT OF ONE FLOW AFFECTING ANOTHER

Figure 4.20: REPRESENTATION OF INDIRECT DAMAGE, via LOSS OF KEY COMPONENTS

simulate the destruction of other economic sectors and resulting shortages. Both the degree of reduction and the recovery time can be specified by the model user. Post-attack reductions in resource demands merely represent another aspect of assumed damage to other sectors. Once again, the extent and duration of the reductions can be user-defined.

The post-attack availability of transportation to each sector is treated differently from other inputs to production. In the model, transportation is broken down into two components: transportation performed using capital internal to a sector (e.g., petroleum products transported through a pipeline owned by an oil company), and transportation performed using capital external to a sector (e.g., coal carried by an independent railroad). How much internal transportation is available to each sector depends on the adequacy of capital within that sector. The availability of transportation from external sources depends on the condition of the non-resource sectors of the post-attack economy.

The model user can retain complete control over the specification of damage for any simulated attack. This is particularly useful in representing surgical, counter-population, or other types of imbalanced attacks. However, the model contains a "default option" that ensures a consistent set of time-phased damage assumptions. Unless the user intervenes, his specifications of an attack on the natural resources sectors are automatically translated into reduced availability of inputs to resource production and reduced demand for resources from other sectors. Thus, via the extent of damage inflicted upon the natural resources sectors, a degree of damage in the remainder of the economy is calculated.

The model can also simulate shifts in policy that precede or follow an attack. Allocation and rationing of scarce resources may suddenly become

active, or be phased in gradually. Wage and price controls can be introduced. Foreign trade can be reduced or eliminated. These and dozens of other policies can be simulated singly, or in combination with other policies.

The user may specify the above drawdowns, transfers, changes in economic conditions, and policy shifts to occur at any time and in any magnitude, on a sector by sector basis. The model can therefore simulate surgical strikes, neutron bomb attacks, multiple attacks, etc. Any number of scenarios and policies can be tested. The model imposes few limitations on the range of the attack scenarios a user can investigate.

E. Data Inputs to the Model

1. Introduction

The System Dynamics approach used to develop the natural resources model is robust and versatile, particularly with respect to data. Data are involved in two fundamentally different ways in the creation, refinement, and use of System Dynamics models. First, there are several categories of user-supplied external inputs to this model:

a. "initial conditions," specifying the values of key variables at the start of a simulation;

b. "functional relationships," describing the strength and nature of the effect of one variable upon another;

c. "time parameters," representing delays, planning horizons, the lifetimes of assets, the term of debts, and certain types of goals (e.g., the number of months of inventory desired);

d. "time-varying input streams," corresponding to variables required by the model's equations but not calculated within the model (e.g., the prices and availabilities of imported resources); and

e. "policy levers," indicating assumptions about attack characteristics, and pre- and post-attack government policies.

Second, historical time-series data for some variables simulated in the model (e.g., production, prices, and many financial variables) are used outside the model in an iterative process of refinement. This process, called model "tuning", is described in Chapter III. As discussed there, tuning is a legitimate and powerful means of model estimation.

The remainder of this chapter elaborates on the five categories of external inputs to the model. It describes key inputs, their derivations, and (where applicable) the conceptual consequences of altering them. Throughout the discussion, the names of parameters as they appear in the natural resources model are shown in parentheses.

2. Initial Conditions

Each equation in the natural resources model defines a relationship among model variables, which causes one of them (the so-called "dependent variable") to increase or decrease over time in response to changes in the other (i.e., "independent") variables. As discussed more fully in Volume II, the DYNAMO simulation software computes a value for each variable at every time increment during the simulation period. The model "bootstraps" itself through time, using the values for variables at one point in time to compute values one time increment later, and so on.

This type of simulation process requires a defined starting point. The state of the system at the beginning of the simulation period is one a class of external inputs to the model known as "initial conditions." Not every variable in a model requires a user-specified initial condition. In general, only stock variables ("levels," as they are called in DYNAMO

nomenclature) require external initialization. Other variables are automatically initialized, based on the specified initial values of the levels.

For the natural resources model, initialization involves inputing a set of 1965 conditions for the four resource sectors. Variables requiring initial conditions include:

a. all balance sheet assets and liabilities, e.g. cash (CASH), value of inventory (VI), book value of capital (BVC), debt (DEBT), and equity (EQ);

b. the price of each category of resources (PRICE);

c. total domestically available resources, i.e., resources in the ground, for each category (RSRCS);

d. resource production (P); and

e. physical stocks of capital equipment (C), buildings (B), resource inventories (INV), materials in use (MIU), recoverable scrap material (RSM), and government resource stockpile (GSTOCK).

Various government statistical sources were used to develop these inputs. It was necessary to aggregate data which, in their "raw" form, are presented in much more detail than required by the natural resources model.

Initial conditions for the balance sheet variables were obtained from Internal Revenue Service data.[10] The IRS data were aggregated along two axes. First, the raw data are broken down by a detailed industry classification. Data for the industries included in each model section (see Figure 4.1) were combined to produce the appropriate sectional numbers. Second, the raw data are presented in a more detailed structure of accounting categories than the model's relatively simple financial equations. Hence, the data had to be aggregated along that dimension as well. For example, the initial conditions for book value of capital were

calculated by summing IRS data for "depreciable assets", "depletable assets", "land", "intangible assets", and "other assets".

Initial conditions for resource prices were compiled from U.S. Department of Labor wholesale price data.[11] Prices for individual commodities were weighted by the amount of the commodity produced in 1965. This was done for as many commodities as possible within each sector, thereby building up a composite weighted-average price for each sector's output.

Initial conditions for production were based on the 1967 input-output study of the U.S. economy.[12] As described earlier, appropriate sectoral numbers were developed by collapsing the detailed input-output table into the industry groups shown in Figure 4.1. Price indices and production growth rates obtained from the Statistical Abstract of the United States[13] were used to "back down" the 1967 input-output data to 1965, and restate them in constant 1970 dollars.

Initial conditions for total domestic resources of each category were calculated from Bureau of Mines data.[14] The Bureau of Mines figures for "proven" and "probable" reserves were used as measures of total domestic resources remaining for production in 1965. Appropriate numbers for each model sector were obtained by summing data for the most important commodities.

Initial conditions for the government stockpiles were determined from FEMA and the Bureau of Mines.[15]

Initial conditions for the other physical stocks mentioned above were estimated from 1967 input-output data and the assumed lifetimes of capital equipment and buildings. For example, the 1965 capital equipment stock in the metallic durable materials sector depends on: 1965 receipts of capital

(calculated from the 1967 data "backed down" to 1965 as described above); the assumed average lifetime of the capital; and the estimated growth in metals production over the years leading up to 1965. In a no-growth situation, new capital would merely replace what was being scrapped, and the stock would be equal to

RATE OF RECEIPT * AVERAGE LIFETIME

In a growth situation, the stock would be less than this amount in proportion to the estimated growth rate.

3. Functional Relationships

In the natural resources model, it is often necessary to say with an equation that the value of one variable depends on the value of another variable in a specific fashion. A linear relationship can be expressed with constant parameters. To represent a non-linear relationship, a DYNAMO "TABLE" function is employed. The working of this feature of the DYNAMO language is described in Volume II of this document. Conceptually, it specifies through a set as X-Y coordinates a curve (of any desired shape) defining the effect of one variable upon another. These relationships comprise another class of internal input to the model.

TABLE functions are shown in Figures 4.9 through 4.11, in connection with the discussion of the production function and, also, in Figure 4.15 regarding the effect of resource depletion on the productivity of capital. Another example of this type of relationship is found in the equations representing the effect of market conditions on price. As described earlier, each natural resource sector calculates a desired price based on perceived per-unit costs and a per-unit desired profit. However, under conditions of relatively high demand and low supply (the so-called

"seller's market"), increased prices can be obtained from consumers. Conversely, competition will depress prices under conditions of low demand and high supply. Further, this effect is both non-linear and non-symmetrical: a large (e.g., 30%) supply shortfall would inflate price entirely out of proportion to a small (e.g., 10%) shortfall; excess supplies would depress price less than shortfalls would increase it, because of a reluctance of producers to sell below cost. All of these concepts are embodied in the TABLE function shown in Figure 4.21.

There are a large number of relationships of this type in the natural resources model. The most important include:

a. the effect of cash adequacy on dividend payments (ECAD) and capital investment (ECAI and EFACI);

b. the effect of expected ROI on capital investment (EPPE and RADP);

c. the effects of import price (EIPDP) and supply/demand balance (ESDP) on domestic price;

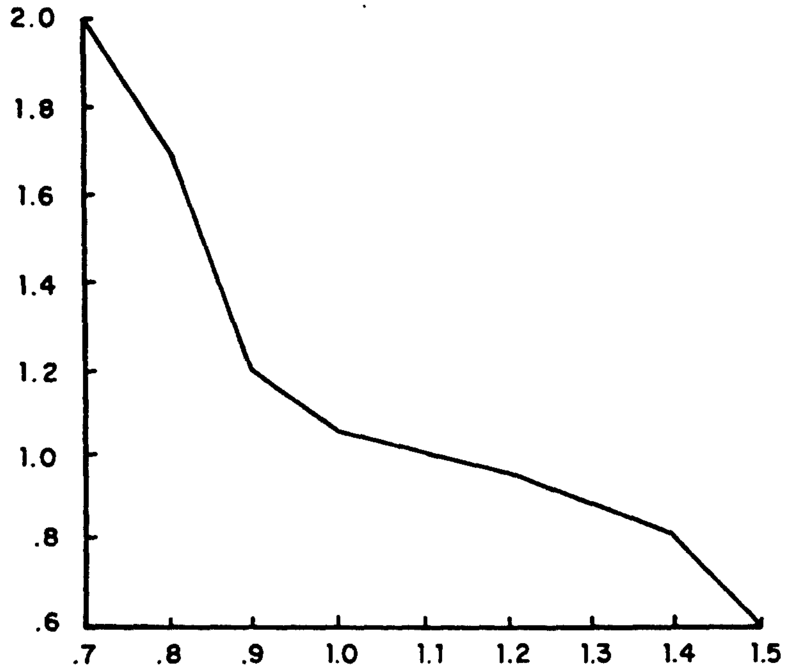
d. the effects of resource depletion (ERDPC), technology (ETCHPC), energy price (EP3PC), and recycling (ERPC) on the productivity of capital;

e. the effects of technology (ETCHPL), building adequacy (EPB), and recycling (ERPL) on labor productivity;

f. the effects of resource prices on demand (EP3PE and EPRD); and

g. the effect of import price relative to domestic price on import demand (DFDIM).

These functional relationships have been estimated by the following process. First, the results of literature reviews, discussions with experts, our previous experience analyzing the natural resource industries, and plain common sense were used to provide an initial estimate of each relationship. For example, in the case of Figure 4.21, it was clear that:



EFFECT OF SUPPLY/DEMAND BALANCE ON PRICE

FIGURE 4.21

the curve sloped from the upper left to the lower right; it passed near the (1,1) point, because by definition when supply and demand were "in balance," this effect is null; and it was relatively flat in the region of the null point.

Once initial estimates of all such relationships were inputted to the model, they were refined by the repetitive process of model "tuning" described in Chapter III. As discussed in that chapter, the process of "tuning" a Systems Dynamics model to historical data is an exercise in the simultaneous estimation of relationships using full information/maximum likelihood methods. This approach is often used in engineering, and is one of the aspects which distinguishes our methodology from classical econometrics.

4. Time Parameters

There are many constant parameters in the natural resources model which have a time dimension associated with them. This category of user-supplied inputs represents delays, planning horizons, the lifetime of assets, the term of debt, and certain types of goals. The most important are:

a. the time to depreciate capital (DEPT);

b. the time to deplete cash for capital investment (TDCCI) and debt repayment (TDCDR);

c. the time to perceive demand (TPD) and supply-demand balance (TPB);

d. the time over which the trend in capital productivity is extrapolated (CPTT);

e. the planning horizon for projecting demand, price, and costs in order to determine future capacity additions (PH);

f. the desired ratio of inventory to demand (ICD) and the minimum ratio before shipments are constrained (ICR);

g. the normal physical lifetime of capital (CLTN) and building (BLT);

h. the normal fraction of scrap recycled (NFSR); and

i. the delay involved in the receipt of capital (CDT).

Most of these parameters have been estimated by the same process that was used to estimate the functional relationships discussed above. In some cases, they could be inferred from reasonably accurate numerical data. For example, the depreciation times were calculated as

BOOK VALUE OF CAPITAL ÷ ANNUAL DEPRECIATION EXPENSE.[16]

The normal fraction of scrap recycled was estimated from Bureau of Mines scrap data.[17]

5. Time-Varying Input Streams

Time-varying inputs are a special use of the DYNAMO "TABLE" function. The independent variable is time. These tables are used to supply data streams to the model, representing factors beyond the model's boundary. Historical interest rates, for example, are one time-varying input. The scope of the natural resources model is limited to the natural resource producing sectors of the U.S. economy. In the stand-alone version, there is no internal banking or capital market sector. Nonetheless, the average interest rates associated with each resource sector's debt is required by several equations. Interest rates over the period 1965 to 1980 are a user-supplied data stream (AIR). Actual data are inputted for the historical period. Interest rates for 1981-2000 are linked to user-specified

inflation assumptions (which can be changed by the user for sensitivity testing and scenario analysis purposes).

Natural resource demands are another very important set of time-varying input streams to the stand-alone model. Almost all final demand (i.e., demand other than from intermediate stages of the producing sector itself) for metallic products, non-metallic durable materials, and non-energy consumable materials comes from outside the natural resource sectors. Only demand for energy products is significant within the natural resources model. The model, however, requires total demand to drive production. The source for demand was the Bureau of Economic Analysis 1967 input-output study.[18] These data points were extrapolated backward to 1965 and forward to 1980 using growth rates which were estimated from financial data and general economic conditions over the historical period. Future growth estimates have been derived from various economic forecasts, including simulations with the U.S. Economic Recovery Model.

Technology is another input stream (TECH). In many ways, the development of a modern economy is dominated by technological innovations and their implementation. Technology defines the processes available for economic activities such as manufacturing, and also determines the baseline efficiencies of all the inputs to the manufacturing process. In other words, technology is the "recipe" of economic activity, specifying the inputs required to achieve a given output, and thereby determining the normal cost of that output. The treatment of technology in the natural resources model is described in Section D.2. A series of indices are used, where 1.0 represents the technology existant in each sector in 1965.

Other important time-varying input streams include:

a. the return on investment from foreign production (FROI);

b. the effects of environmental regulations on the productivity of capital (EEOPC and EEIPC) and labor (EEOPL and EEIPL);

c. the level of environmental technology required by government regulations (RETECH);

d. import prices (IPT)[19] and availability (AIM); and

e. price indices for capital (CPRNDX) and labor (LPRNDX).[20]

As noted above, all time-phase inputs require estimations of their behavior beyond the historical period, that is, for 1980-2000. Each behavior pattern specified by the user for that period embodies a given assumption about general and specific economic conditions in the future. There is no "correct" path; there are only various testible scenarios.

6. Policy Levers

The last class of user-supplied data inputs are those that dictate the attack scenario and recovery policies during each simulation. This type of input includes magnitudes of destruction; availability of labor, capital, transportation, and resource imports post-attack; and pre- and post-attack recovery policies.

How to set each policy depends on how the specific equation are structured. For example, to invoke rationing is a three-stage process. First, the start date for rationing must be specified. Second, the rationing duration must be specified, in years. Finally, the magnitudes of rationing (the amount of output made available to each requesting sector) must be specified. On the other hand, respecifying how government

stockpile releases are formulated entails changing the value of a single constant.

7. Other Data Inputs

There are many constant parameters throughout the natural resources model, each with a conceptual framework justifying its existence and use. A number of these were derived in a straightforward way from government data sources. Income tax rates (ITR), for example, were inferred from IRS data.[21] Dividend rates (DRN) and property tax rates (TR) were calculated from the same source. The maximum debt/equity ratio allowable by lenders (MAXDE) was estimated by examining debt and equity data sector by sector. Labor markups (LCM) representing fringe benefits, overhead costs, and other sectoral expenses not explicitly modeled were estimated from IRS cost data and Labor Department average wage data.[22]

Some inputs to the model are fractions, splitting demand or production into several components (FDA, etc.). The basis for many of these parameters is the input-output study.[23] Based on the input-output coefficients, total demand for resources was split and allocated via constants derived from the input-output table. Finally, a set of conceptually important parameters, the fraction of each sector's gross production available for shipment outside the sector (FPO), were estimated directly from the input-output table. These parameters "net out" of each sector's output the quantity of intermediate products consumed within the producing sector. The fraction of sectoral revenues from outside the sector (FRO), is the financial parallel to the fraction of production parameters discussed above. These fractions, once again, "net out"

intra-sectoral transactions. They were estimated from IRS, input-output, and price data as:

(NET PRODUCTION * PRICE) ÷ TOTAL SECTORAL REVENUES.

Finally, the natural resources model contains parameters representing the "normal" productivities of labor, capital, and energy; that is, the base productivities before the variable effects of technology, environmental regulations, depletions, recycling, etc. These constants were estimated from 1965 data as, for example

TOTAL SECTORAL LABOR ÷ TOTAL SECTORAL OUTPUT.

V. USE AND APPLICATION OF THE MODEL

A. Use of the Model

1. Computer Requirements

The natural resources model is large, though it is much smaller than the overall U.S. recovery model. The use of the model is straightforward and economical. It is written in the DYNAMO simulation language, which is efficient and user-oriented. On an IBM/370 computer, using the DYNAMO III/370 compiler, a typical simulation requires 400 kilobytes of main storage and 5-6 seconds of central processer time, for an average cost per simulation (at current commercial rates) of about seven dollars.

2. Time Scale

The model is initialized to begin each simulation in 1965. Without modification, it may be simulated as far into the future as a user desires. All of the future projections presented in this report run until 2000. The computation interval (time step) of the model is one-sixteenth of a year (i.e., about three weeks). This interval may be shortened by the user with no modification of the model if a more detailed time scale is needed. The model can be re-initialized to begin simulations at any date after 1965. With the DYNAMO III/370 software, such a re-initialization is done automatically; otherwise, several man-days of effort are necessary. Starting the model before 1965 would require development of input-output data for the starting time, and, therefore, would probably be a major undertaking.

3. Output

Any model variable may be printed at any time interval during the simulation. The user can re-specify output without modifying or recompiling the model.

4. Inputs Required and Their Modification

The external inputs required by the natural resources model are described in Chapter IV. A complete set of these inputs is built into the model, and produces the base simulation (see Chapter VI). Other simulations are the result of selective modification of model inputs. Respecifying data inputs is the way in which a model user changes assumptions about attack scenarios, government policies, and economic conditions not calculated within the natural resources model (e.g., inflation, import availabilities). Varying these inputs produces a virtually unlimited number of scenario, policy, and sensitivity tests.

B. Applications of the Model

The natural resources model has been designed for the following applications:

1. Attack Scenarios

The model allows sophisticated representation of a large variety of attack scenarios, completely at the discretion of the user. Surgical, maximum-kill, and many other kinds of attack on the four natural resource sectors of the economy may be specified. In addition, the robustness and detail of the model allow representation of multiple strikes, pre-attack

surges, and mobilization. It should be re-emphasized that the "attack" inputs to the model are damage and disruption, expressed in economic and social terms. The model does not convert weapons laydown patterns into death and destruction; this must be done by the user. However, within the level of detail of the model, the choice of attack scenarios is limited only by the imagination of the user.

2. Sensitivity to Damage

For any scenario, the model calculates the likely consequences of the attack for the natural resource sectors of the U.S. economy and post-attack evolution of these sectors. By holding government policies constant and varying the attack scenario, the user may test the sensitivity of the economy to various kinds of attacks. Such tests are a useful starting point for identifying critical areas for protection and recovery policies, and for determining worst-case scenarios for planning or gaming exercises.

3. Policy Tests

For any attack scenario, the user may specify a wide variety of civil defense and recovery policies, including building shelters, dispersion, hardening, stockpiling, import substitution, relocation, mobilization, central planning, financial assistance, resource allocation, rationing, conservation, and recycling. The user may test existing policies or develop new ones. The efficiency of the model encourages testing of new ideas and scenarios that would otherwise be impractical to evaluate.

4. Optimization of Policies

For any given attack scenario, policy inputs may be varied in a systematic way to discover the optimum set of policies. The user may specify any desired function as the "goodness" measure to be maximized. This optimization criterion may be simple (such as the number of years to reattain pre-attack levels of production) or complex. It should be emphasized, however, that tests with the model (see Chapter VII) strongly suggest that different recovery policies are required for different attacks. Therefore, unless the nature of the attack is known in advance, there is no single optimum policy set. Rather, there is a collection of optimum post-attack contingency plans and a set of robust pre-attack policies which are preferable over a broad range of possible attacks. The model is useful for identifying them.

5. Design of Recovery Indicators

By examining the detailed output of the model for various attack and recovery scenarios, the user can identify key measures of the true state of the recovery process. Such measures would improve the reliability of post-attack monitoring and the likelihood of selecting the most effective recovery policies. The model can be used to determine priorities for information collection and analysis during recovery. Because the collection of information post-attack will be difficult, uncertain, and expensive, it is important to make every piece of information count. The model can be used to reduce the required information, and make full use of what is acquired.

6. Insights Into Targeting

Although the model is obviously not of direct application to the targeting of U.S. weapons, it can yield insights into the general use of strategic weapons and diplomatic policies to effect maximum damage, taking into account economic, political, and psychological factors. The model's representation of time-varying and self-reinforcing phenomena also is valuable, as it allows the exploration of ideas of using weapons effects to trigger self-destructive instabilities to achieve maximum leverage from a given capability.

The above applications motivated development and refinement of the natural resources model. Chapters VI and VII illustrate the potential of the model. Chapter VIII summarizes the conclusions which may be drawn from experiments performed to date.

VI. THE BASE SIMULATION

This chapter presents the basic simulation of the natural resources model. The simulation described here and those discussed elsewhere in the report are all produced with the four-sector, stand-alone version of the model.

The base simulation starts in 1965 and runs through 2000. The reason for starting in 1965 is to evaluate how well the model reproduces the actual behavior and performance of the natural resource sectors of the U.S. economy over the past fifteen years. The model's ability to reproduce historical performance is an important factor in assessing how much confidence one should have in its projections of the future.

A. Purposes of the Base Simulation

The base simulation serves two purposes:

1. It facilitates evaluation of the model. Simulation results for the period 1965 to 1980 have been compared with actual historical data. The model represents past economic performance within reasonable limits, consistent with the specific goals of this project (see Section II.A).

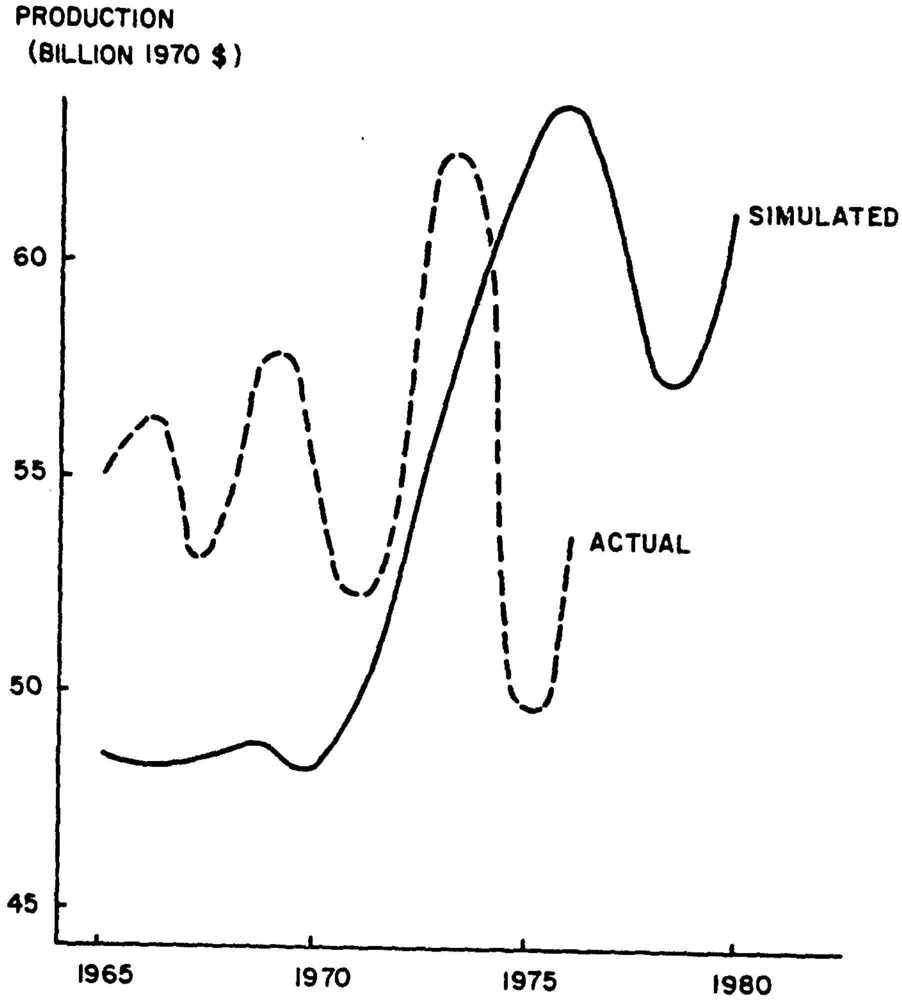
2. It provides a benchmark against which the consequences of alternative policies and scenarios can be compared. The primary use of the model is to answer "what if" questions. For example, what if the U.S. Government adopted a certain resource stockpiling program: how would it affect pre-attack resource markets and post-attack economic recovery? In order to answer such questions, alternative projections incorporating the prospective policies are compared with the base simulation.

B. Results and Their Accuracy

The four-sector natural resources model contains over 2000 variables. One can obtain numerical or graphic output for any or all of them, at user-selected intervals (e.g., quarterly, annually), for any specified combination of attack scenarios and government policies, at a cost well below ten dollars. Therefore, although it is instructive to focus on a few key variables for the presentation of results in this report, it is both cheap and convenient to inspect the detailed behavior of any part of the model. Very detailed examination is useful in order to look for errors, or to evaluation why a simulation does what it does. This explanation is intended to avoid the misimpression that the variables graphed in the following figures are the only ones which can be simulated or examined.

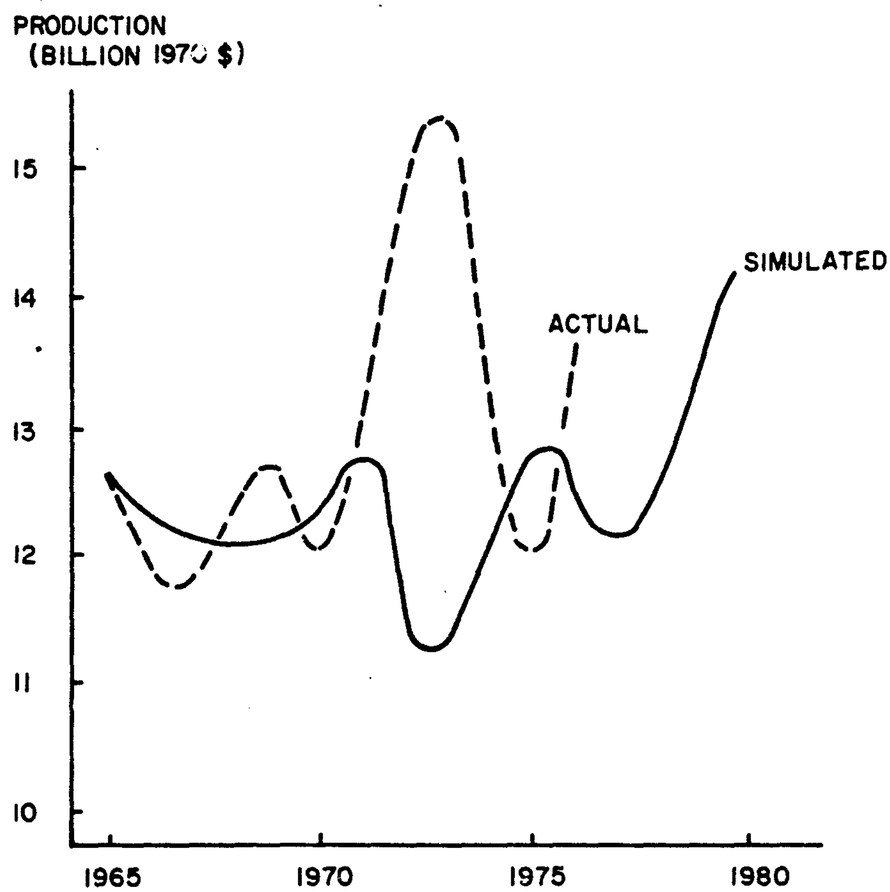
Figures 6.1 through 6.4 show the simulated values of production for each natural resources sector over the period 1965-1980. Superimposed on each graph are data from historical estimates of these same variables. Figures 6.5 and 6.6 contain simulated financial variables for each sector in 1970 and 1974, with corresponding historical data. Figure 6.7 presents simulated and historical resource price indices.

The correspondence between data is reasonably close, within ±10% for many important variables, although there are a few larger discrepancies. There are two reasons why the "fit" of the model to the historical data is not more precise. First, it was not the goal of this project nor the purpose of the natural resources model to engage in high-accuracy short-term forecasting. We strongly believe in the maxim "different models for different purposes." Hence, we chose not to build into this model much of the detailed causal structure necessary to explain short-term economic



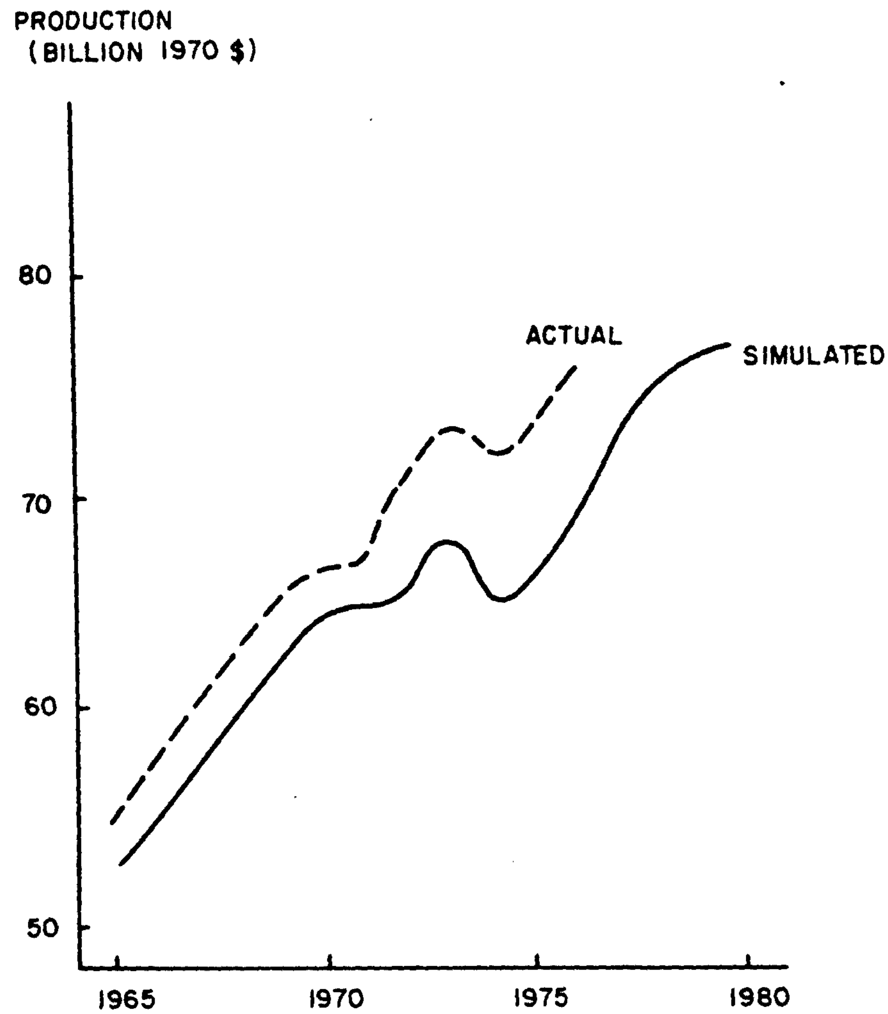
METALLIC DURABLE MATERIALS
HISTORICAL COMPARISON OF SIMULATED VS. ACTUAL VALUES

FIGURE 6.1



NON-METALLIC DURABLE MATERIALS
HISTORICAL COMPARISON OF SIMULATED VS. ACTUAL VALUES

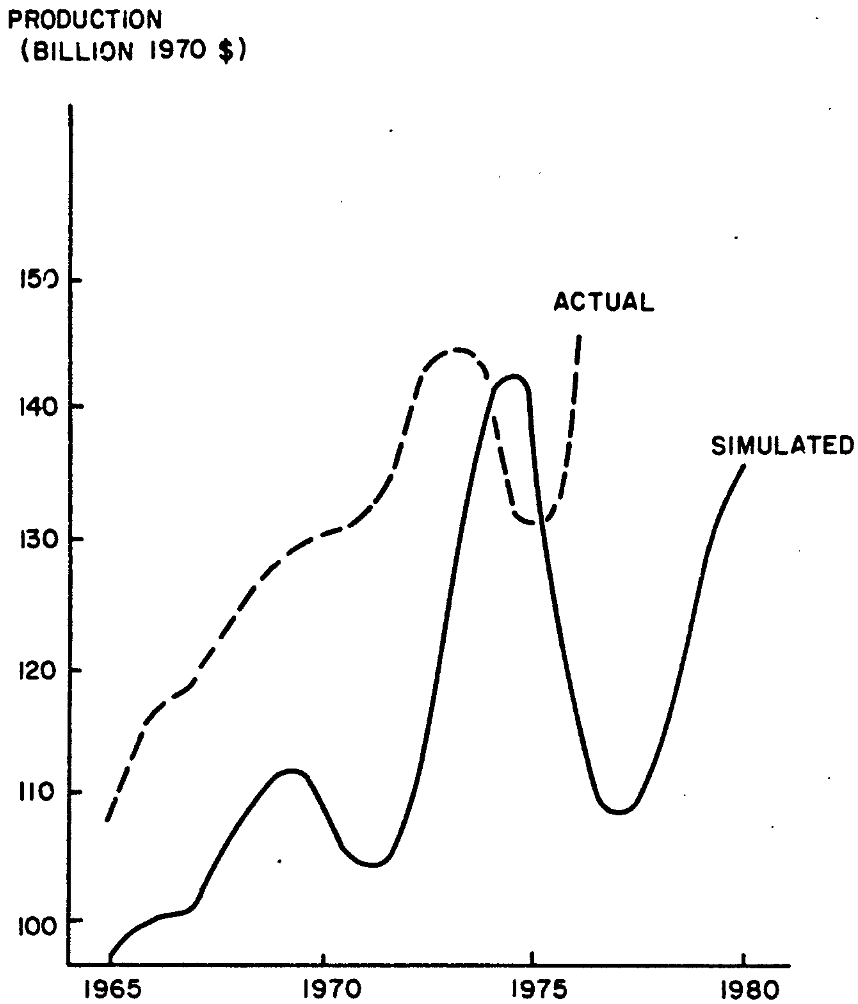
FIGURE 6.2



ENERGY PRODUCTS

HISTORICAL COMPARISON OF SIMULATED VS. ACTUAL VALUES

FIGURE 6.3



NON-FUEL CONSUMABLE MATERIALS
HISTORICAL COMPARISON OF SIMULATED VS. ACTUAL VALUES

FIGURE 6.4

1970

	METALLIC DURABLE		NON-METALLIC DURABLE		ENERGY COMMODITIES		NON-FUEL CONSUMABLE	
	SIMULATED	ACTUAL*	SIMULATED	ACTUAL	SIMULATED	ACTUAL	SIMULATED	ACTUAL
REVENUES	49.7	49.0	18.9	18.7	126.3	125.9	141.1	141.8
COST OF SALES	44.2	43.4	17.1	16.2	88.5	91.0	130.9	141.8
DEPRECIATION	2.4	3.1	1.2	1.2	13.7	12.3	6.0	6.8
INTEREST	1.3	1.2	.5	.3	5.8	4.9	3.1	2.5
CASH	20.3	23.3	6.9	6.3	73.5	58.3	55.5	54.4
BOOK VALUE OF CAPITAL	24.3	29.3	9.4	9.5	164.5	163.0	47.8	57.3
DEBT	28.5	30.7	11.2	7.9	129.2	118.9	67.8	63.5
EQUITY	28.3	31.1	10.3	10.6	127.8	111.6	59.4	72.3

(ALL VALUES IN BILLION $)

FIGURE 6.5
COMPARISON OF SIMULATED VS. ACTUAL VALUES

*Source: IRS CORPORATE INCOME TAX RETURN, 1970

1974

	METALLIC DURABLE SIMULATED	ACTUAL*	NON-METALLIC DURABLE SIMULATED	ACTUAL	ENERGY COMMODITIES SIMULATED	ACTUAL	NON-FUEL CONSUMABLE SIMULATED	ACTUAL
REVENUES	97.1	94.7	32.1	31.8	266.9	385.3	251.9	256.3
COST OF SALES	79.8	82.0	25.1	27.5	147.2	303.9	226.5	224.1
DEPRECIATION	3.7	4.0	1.6	1.8	19.5	28.0	10.5	10.3
INTEREST	2.2	2.0	.6	.7	9.3	9.4	5.1	4.5
CASH	34.0	31.7	9.0	10.6	106.1	121.8	77.1	76.8
BOOK VALUE OF CAPITAL	37.3	41.7	12.6	13.4	233.4	246.3	84.3	77.8
DEBT	45.9	44.4	12.7	13.5	197.7	216.6	109.4	97.0
EQUITY	42.0	41.5	13.0	14.8	172.1	170.7	97.8	94.9

(ALL VALUES IN BILLION $)

FIGURE 6.6
COMPARISON OF SIMULATED VS. ACTUAL VALUES

*Source: IRS CORPORATE INCOME TAX RETURN, 1974

PRICE INDICES

	METALLIC DURABLE		NON-METALLIC DURABLE		ENERGY COMMODITIES		NON-FUEL CONSUMABLE	
	SIMULATED	ACTUAL*	SIMULATED	ACTUAL	SIMULATED	ACTUAL	SIMULATED	ACTUAL
1966	.85	.84	.89	.87	.90	.92	.91	.91
1970	1.01	1.00	1.05	1.00	1.05	1.00	1.04	1.00
1974	1.58	1.47	1.58	1.35	1.99	1.97	1.42	1.40
1978	2.07	1.95	2.38	1.97	3.15	3.05	2.29	1.86

(1970 = 1.00)

FIGURE 6.7

COMPARISON OF SIMULATED VS. ACTUAL VALUES

*Volume-weighted avg. price index; derived from DEPARTMENT OF LABOR WHOLESALE PRICE INDICES

fluctuations. And beyond the point presented here, we chose not to expend additional resources fine-tuning this model's parameters to achieve closer conformity with the historical data (although further progress in that regard definitely is feasible). Our goal in this project is to evaluate the vulnerability of the U.S. economy to damage to its natural resource sectors, and to examine natural resource-related policies which might expedite post-attack economic recovery. Comparisons of alternative scenarios and policies (as the reader will see in Chapter VII) involve large differences in economic performance over periods of a decade or more — even the difference between recovery and no recovery — rather than small differences over a few years.

Second, the data themselves are far from perfect. For example, we uncovered significant inconsistencies between data in the Department of Commerce input/output study[1] and financial data from the Internal Revenue Service[2]. The input/output study implicitly treats each sector of the economy as a single aggregate "firm"; the net magnitude of intra-sectoral transactions is reported as "the amount of each sector's output consumed by itself." The IRS data, on the other hand, results from the summing of the tax returns of many individual firms. Here, the gross magnitude of intra-sectoral transactions is reported, i.e., the sale of metal ore to a refiner, and of refined metal to a fabricator, are added together in calculating total sectoral sales revenues. Hence, the sales data from the IRS are not equal to the consumption data from the input/output (adjusted for inventory changes) times price. Cost data and, therefore, profits, cash flows, and other financial variables are comparably "off". To reconcile these two important data sources, we had to estimate for each sector the fraction of total sector revenues which come from internal

transactions and the corresponding fraction of revenues from outside the sector. Overall, we found enough anomalies and inconsistencies in the historical data that the meaningfulness of a more precise fit can be questioned. Clearly, it is unwise to make comparisons between model and data at a precision greater than the accuracy of the data themselves.

The most important idea to be drawn from the preceding discussion is this: The base simulation of the natural resources model is intended to serve as a reference point for comparing the consequences of alternative attack scenarios in combination with alternative U.S. Government policies. The historical accuracy of the model (as presented in this chapter), the reasonableness of its structure and numerical assumptions (as described in Chapter IV), and the plausibility of its behavior under extreme conditions (as discussed in Chapter VII) together provide evidence that one can have confidence in the general conclusions developed from such simulation experiments.

VII. ANALYSIS OF ATTACK SCENARIOS AND RECOVERY POLICIES

A. Introduction

The natural resources model was developed as a tool to assess the vunerability of the U.S. natural resource sectors to various degrees and types of damage. The model can be used to analyze the impact of resource availability and U.S. Government natural resource policy on post-attack economic recovery. The model is capable of simulating a wide range of attack types, and dozens of possible recovery policies. By combining policies and attacks, the potential of the model to analyze the recovery process is vast.

All possible alternatives were not tested with the model. Such an undertaking is beyond the scope of the project, and, in any event, would have produced an overwhelming mass of data. Rather, a number of alternative attack scenarios and policies were selected to indicate the model's breadth, and to identify key issues in economic recovery. Testing policies and scenarios not discussed in this chapter is a straightforward task.

The remainder of this chapter discusses the illustrative simulations performed with the natural resources model. Section B is an overview of all of the tests. Section C describes the attack scenarios, while the recovery policy experiments are reviewed in detail in Section D. Combinations of several recovery policies are discussed in Section E.

B. Overview

1. Measures of Recovery

Each test simulation with the natural resources model was performed over the period 1980 to 2000. In the experiments presented here, the nuclear attack was assumed to occur in 1981. This is to facilitate comparison of alternative scenarios and policies. Of course, model users may specify any attack timing they desire.

Output of all model variables can easily be obtained from any simulation. However, for clarity and consistency, it is useful to focus on a few key indicators of recovery. These include adequacy of resource supplies (including imports, if available), adequacy of domestic resource production, and time required to reach pre-attack levels of production and imports.

Time to achieve pre-attack levels of production is a measure of recovery often used in nuclear strategy literature. This measure is intended to indicate how long it would take for the economy to regain its pre-attack economic strength. While useful for thinking about the economy as a whole, in certain scenarios it alone is an incomplete indicator of sectoral recovery. Less than pre-attack production of certain commodities may satisfy post-attack demands. However, rebuilding may require more of other sectors' outputs than under normal, pre-attack conditions. Many scenarios exist in which natural resource supplies and demands are balanced, inflation is stabilized, growth is cohesive, but the overall economy does not regain its pre-attack production levels for several decades.

All of this suggests another important recovery indicator, i.e., the current ratio of available resources to total demand. A nuclear attack of

any magnitude will result in unprecedented economic damage. However, each destroyed entity (such as a unit of capital or a worker) must be regarded as a supplier to the economy and a demander of the economy. Destruction, then, both reduces the economy's potential for production, and the economy's need for production. A very significant aspect of recovery is the balance among the outputs and requirements of the various sectors. While the amount of time required to regain pre-attack economic levels is an absolute measure of the effects of nuclear war, the "production adequacy" of each sector to satisfy the demands of other sectors is a critical relative measure of recovery. This type of measure indicates whether overall recovery is being impeded by insufficient production of various natural resources.

Another relative measure of recovery is "delivery adequacy." While production adequacy indicates the potential of the economy to satisfy demand, delivery adequacy measures the shortfall in physically filling orders for sectoral output. This can differ greatly from production adequacy. It might be higher because of producer inventories, imports, and government stockpile releases; it might be lower because of transportation unavailability.

Analyzing model experiments is an iterative process. Each test is compared both to the "base simulation" (see Chapter IV), and to any other simulations with similar assumptions. Two of the measures mentioned above — time to achieve pre-attack production and production adequacy — are used for this purpose in the summary tables in Sections 7.C and 7.D. The base simulation serves as a particularly useful benchmark against which alternative policies and scenarios can be compared. It is a projection

into the future assuming no attack and no change in U.S. Government policies. Figure 7.1 shows base simulation output for production of the metals sector and the energy sector.

2. Scenarios

The following is a list of the attack scenarios and recovery policies which will be discussed in this chapter. The assumptions used to create each simulation are summarized. The first six scenarios are various types of attacks with no change in government policies. The subsequent scenarios test various recovery policies in combination with one of the attacks.

SCENARIO I: LOW DAMAGE ATTACK

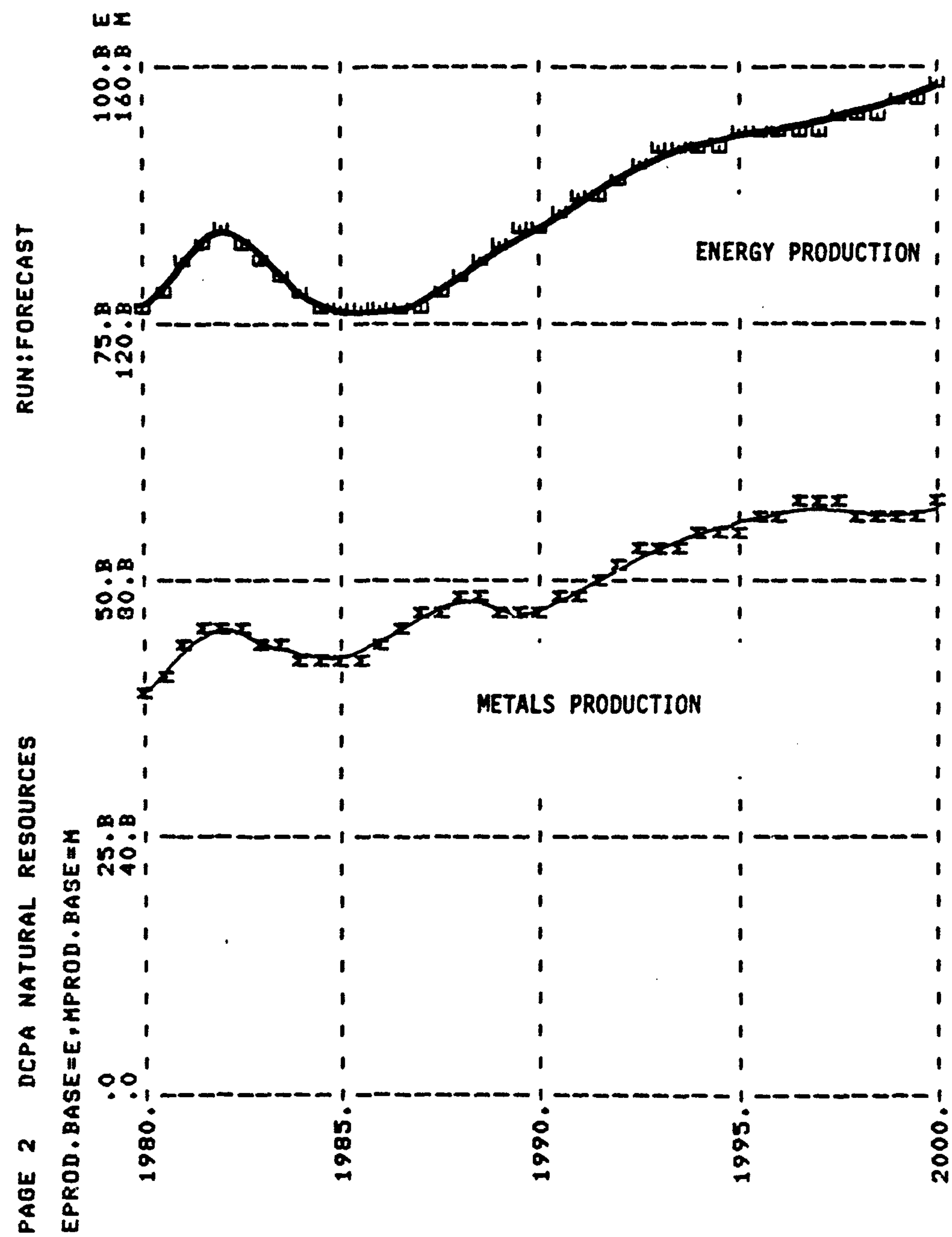
- 10% of inventory, capital and buildings destroyed in all natural resources sectors.
- Imports interrupted for five years for consumable materials; one year for durable materials.
- Inflation at 40% post attack, dropping to 8% after 6 years.
- 10% reduction in demand for natural resources.
- 5% reduction in availability of labor and capital.

SCENARIO II: LOW NATURAL RESOURCES DAMAGE, HEAVY DAMAGE TO REMAINDER OF ECONOMY

- 10% of inventory, capital and buildings destroyed in all natural resources sectors.
- Imports interrupted for five years for consumable materials; one year for durable materials.
- Inflation at 40% post attack, dropping to 8% after 6 years.
- 50% reduction in demand for natural resources.
- 50% reduction in availability of labor and capital.

BASE SIMULATION

FIGURE 7.1



SCENARIO III: SURGICAL STRIKE

- 50% of inventory, capital and buildings destroyed in the energy sector.
- 10% of inventory, capital and buildings destroyed in the other natural resources sectors.
- Imports interrupted for five years for consumable materials; one year for durable materials.
- Inflation at 40% post-attack, dropping to 8% after 6 years.
- 10% reduction in demand for natural resources.
- 8% reduction in availability of labor and capital.

SCENARIO IV: HYPERSURGICAL STRIKE

- 50% of inventory, capital and buildings destroyed in the energy sector.
- 5% of inventory, capital and buildings destroyed in the other natural resources sectors.
- Imports interrupted for five years for consumable materials; one year for durable materials.
- Inflation at 40% post-attack, dropping to 8% after 6 years.
- 10% reduction in demand for natural resources.
- 8% reduction in availability of labor and capital.

SCENARIO V: NEUTRON BOMB ATTACK

- 5% of inventory, capital and buildings destroyed in all natural resource sectors.
- Imports interrupted for five years for consumable materials; one year for durable materials.
- Inflation at 40% post-attack, dropping to 8% after 6 years.
- 50% reduction in demand for natural resources.
- 50% reduction in availability of labor.
- 3% reduction in availability of capital.

SCENARIO VI: HEAVY DAMAGE

- 40% of inventory, capital and buildings destroyed in all natural resource sectors.
- Imports interrupted for five years for consumable materials; one year for durable materials.
- Inflation at 40% post-attack, dropping to 8% after 6 years.
- 40% reduction in demand for natural resources.
- 15% reduction in availability of labor and capital.

All recovery policy tests incorporate attack Scenario III (Surgical Strike) as the determinant of damage. These attack characteristics are:

- 50% of inventory, capital and buildings destroyed in the energy sector.
- 10% of inventory, capital and buildings destroyed in the other natural resource sectors.
- Imports interrupted for five years for consumable materials; one year for durable materials.
- Inflation at 40% post-attack, dropping to 8% after 6 years.
- 10% reduction in demand for natural resources.
- 8% reduction in availability of labor and capital.

In addition, the following scenarios include one or several recovery policies.

SCENARIO VII: RELEASE CURRENT STOCKS

- Release of actual 1981 government stockpiles according to perceived need of sectors for stockpiled material.

SCENARIO VIII: RELEASE OF HYPOTHETICAL STOCKS

- Assumed existence of government stockpiles of metals and energy products equal to approximately 50% of pre-attack annual demand.

- Release of stockpiles according to perceived need of sectors for stockpiled material.

SCENARIO IX: POST-ATTACK STOCKPILE BUILDING

- Building stockpiles to approximately 50% of simulated pre-attack annual demand.

SCENARIO X: NO ENVIRONMENTAL REGULATIONS

- Elimination of environmental regulations beginning one year post-attack until the end of the simulation.

SCENARIO XI: WAGE AND PRICE FREEZE

- Freeze prices at pre-attack levels for five years post-attack.

- Lower inflation than in other simulations.

SCENARIO XII: WAGE FREEZE AND PRICE LIMITATIONS

- Prices set at attack time to a value midway between pre-attack price and the highest price obtained in a non-price freeze simulation.

- Inflation lower than in other simulations.

SCENARIO XIII: FINANCIAL CONSIDERATIONS -- SUBSIDIES AND BORROWING

- Government cash subsidies of $100 billion over ten years to the metals sector, $25 billion over ten years to the non-metals durable materials sector, $500 billion over ten years to the energy sector, and $250 billion over ten years to the non-energy consumable materials sector. Subsidies begin in 1985, four years post-attack.

- Debt/equity limits on borrowing relaxed for twenty years post-attack.

SCENARIO XIV: FINANCIAL CONSIDERATIONS — TAXATION

- Income taxes are decreased by 40% between attack time and 1986, and by 10% between 1986 and 1991.

SCENARIO XV: COMBINATION OF SCENARIOS XIII & XIV

- Government cash subsidies of $100 billion over ten years to the metals sector, $25 billion over ten years to the non-metals durable materials sector, $500 billion over ten years to the energy sector, and $250 billion over ten years to the non-energy consumable materials sector. Subsidies begin in 1985, four years post-attack.
- Debt/equity limits on borrowing relaxed for twenty years post-attack.
- Income taxes are decreased by 40% between attack time and 1986, and by 10% between 1986 and 1991.

SCENARIO XVI: COMBINATION OF SCENARIOS XII, XIII, AND XIV

- Prices set at attack time to a value midway between pre-attack price and the highest price obtained in a non-price freeze simulation.
- Inflation lower than in other simulations.
- Government cash subsidies of $100 billion over ten years to the metals sector, $25 billion over ten years to the non-metals durable materials sector, $500 billion over ten years to the energy sector, and $250 billion over ten years to the non-energy consumable materials sector. Subsidies begin in 1985, four years post-attack.
- Debt/equity limits on borrowing relaxed for twenty years post-attack.
- Income taxes are decreased by 40% between attack time and 1986, and by 10% between 1986 and 1991.

SCENARIO XVII: COMBINATION OF SCENARIOS X, XII, XIII, AND XIV

- Elimination of environmental regulations beginning one year post-attack until the end of the simulation.
- Prices set at attack time to a value midway between pre-attack price and the highest price obtained in a non-price freeze simulation.
- Inflation lower than in other simulations.

- Government cash subsidies of $100 billion over ten years to the metals sector, $25 billion over ten years to the non-metals durable materials sector, $500 billion over ten years to the energy sector, and $250 billion over ten years to the non-energy consumable materials sector. Subsidies begin in 1985, four years post-attack.

- Debt/equity limits on borrowing relaxed for twenty years post-attack.

- Income taxes are decreased by 40% between attack time and 1986, and by 10% between 1986 and 1991.

C. Discussion of Attack Scenarios

Six attack scenarios are described in this chapter. These are: a low-damage attack on the whole economy; low-damage to the natural resources sectors but high-damage to the remainder of the economy; a surgical strike targeting the energy sector, but with "spill-over" damage to other sectors; a hypersurgical strike targeting the energy sector, but leaving the other natural resource sectors nearly intact; a neutron bomb attack on the whole economy; and a heavy damage attack on the whole economy. Each attack includes other assumptions aside from damage. A high-post attack inflation rate is assumed. Furthermore, post-attack imports are assumed to be interrupted in all attack scenarios.

The results of the simulations are summarized in Table 7.2. These tables give output data for the metals sector and the energy sector as representative of total model behavior. Several measures are used to indicate the outcome of each scenario: time (in years) to regain pre-attack production; production adequacy (output capacity divided by total demand) one, two, three, and seven years post-attack; and the "trough" value (i.e., the poorest) production adequacy and its date of occurance.

SIMULATION RESULTS FOR ALTERNATIVE SCENARIOS

ATTACK SCENARIOS

SCENARIO	METALS SECTOR: TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	METALS SECTOR: PRODUCTION ADEQUACY IN 1982	1983	1984	1989	METALS SECTOR: LOWEST VALUE (DATE)	ENERGY SECTOR: TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	ENERGY SECTOR: PRODUCTION ADEQUACY IN 1982	1983	1984	1989	ENERGY SECTOR: LOWEST VALUE (DATE)
Base Forecast	-	.93	.90	.87	.88	.86 (1985)	-	1.05	1.04	1.01	1.00	1.00 (1989)
I. Low Damage Attack	5	.74	.82	.87	.91	.71 (1985)	11	.98	.90	.84	.92	.81 (1985)
II. Low Resources Damage, Heavy Elsewhere	22*	.56	.66	.57	.81	.56 (1982)	25*	.79	.71	.71	.86	.71 (1984)
III. Surgical Strike	6	.56	.68	.71	.91	.56 (1982)	12	.76	.72	.67	.94	.65 (1985)
IV. Hypersurgical Strike	6	.52	.70	.71	.92	.52 (1982)	12	.74	.70	.67	.94	.67 (1984)

* estimated from slope of recovery at end of simulation 19 years post-attack

TABLE 7.2

SIMULATION RESULTS FOR ALTERNATIVE SCENARIOS

ATTACK SCENARIOS (CONT'D)

SCENARIO	METALS SECTOR: TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	METALS SECTOR: PRODUCTION ADEQUACY IN 1982	1983	1984	1989	LOWEST VALUE (DATE)	ENERGY SECTOR: TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	ENERGY SECTOR: PRODUCTION ADEQUACY IN 1982	1983	1984	1989	LOWEST VALUE (DATE)
Base Forecast	-	.93	.90	.87	.88	.86 (1985)	-	1.05	1.04	1.01	1.00	1.00 (1989)
V. Neutron Bomb Attack	15	.57	.69	.64	.85	.57 (1982)	16	.83	.74	.77	.88	.74 (1983)
VI. Heavy Damage	13	.57	.71	.72	.85	.57 (1982)	18	.92	.83	.75	.85	.62 (1986)

TABLE 7.2 (Cont.)

These tables serve only to highlight the range of attack scenarios tested with the model and their consequences. Additional simulation output is with the detailed discussions of some scenarios. Output in tabular or graphical form can be obtained for any model variable, if so desired.

SCENARIO I: LOW-DAMAGE ATTACK

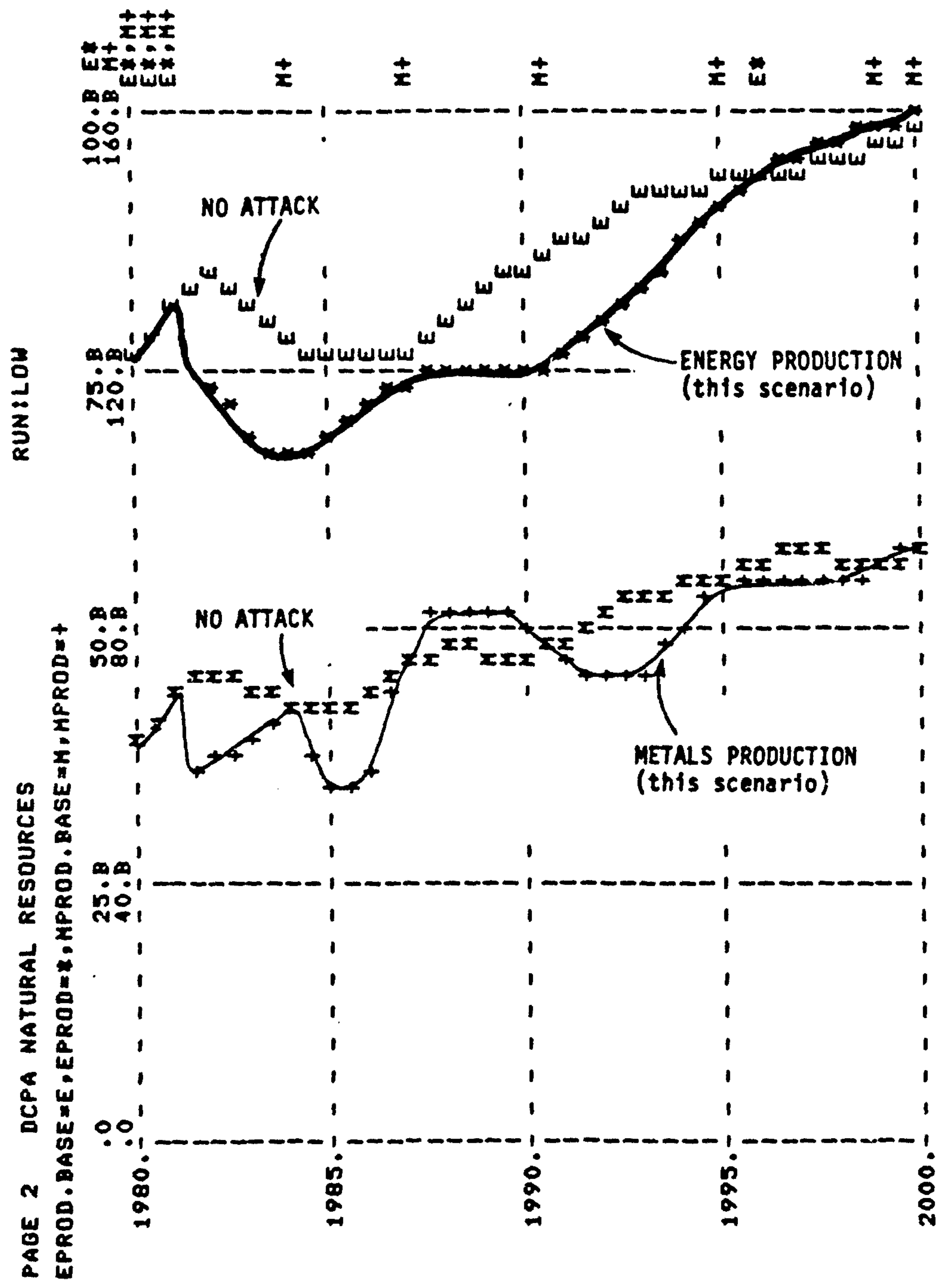
Figure 7.3 shows the results of the low-damage scenario. The natural resource sectors are able to recover from such an attack without serious problems.

Two factors explain this relatively trouble-free. First, none of natural resource sectors experiences a cash crisis. In general, post-attack economic growth is cash-constrained. Massive amounts of capital goods are needed post-attack, both to replace destroyed equipment and to replace surviving equipment which subsequently wears out. This equipment must be obtained from manufacturers, and paid for. The capital investment is a large financial strain on all of the natural resource sectors, particularly in an inflationary environment. The amount of cash available to each sector post-attack from internal cash flow (i.e., retained earnings plus depreciation) has a crucial bearing on recovery.

Second, all natural resource sectors are energy consumers, including the energy sector itself. The recovery of the energy sector allows powerful economic growth mechanisms to begin working. Increases in energy production increase the adequacy of energy as an input to the energy sector, which further increases energy production. Concurrently, more energy becomes available to other sectors. They too increase their production and receive more revenue from the sale of their outputs. These extra revenues

SCENARIO I: LOW DAMAGE ATTACK

FIGURE 7.3



allow more energy and capital to be purchased and used to increase production.

In this low-damage scenario, destruction is insufficient to block these recovery dynamics. Sectors can borrow enough to circumvent serious financial shortfalls. The energy sector never has a critical problem of energy input shortage. Energy remains sufficiently available to the other sectors that growth can continue shortly after the attack.

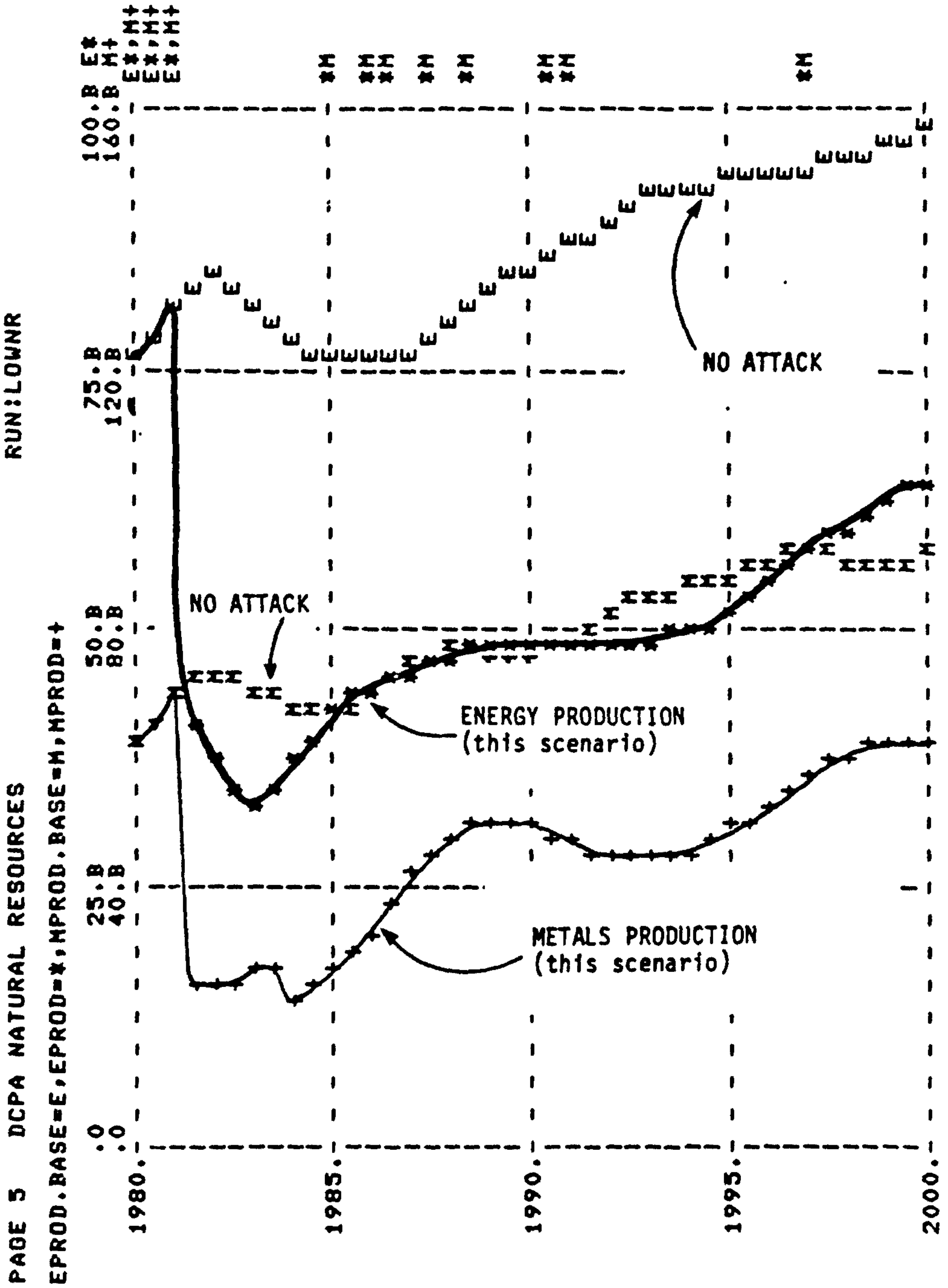
SCENARIO II: LOW NATURAL RESOURCES DAMAGE, HEAVY DAMAGE TO REMAINDER OF ECONOMY

This scenario illustrates a key aspect of post-attack recovery. Even undamaged sectors will suffer serious production problems if the attack elsewhere is severe enough. Here, destruction of the natural resource sectors is light, while the remainder of the economy is damaged severely. As a result, availability of capital and labor is highly constrained. Transportation is inadequate. Demand for resources is reduced because of damage to consuming sectors. The net impact on the natural resource sectors is dramatic, with severe short-term production inadequacy and slow overall recovery. Even though the natural resource sectors are just lightly damaged, they cannot replace deteriorating equipment, nor replenish killed and injured labor.

Figure 7.4 shows graphic output for the metals and energy sectors under this scenario.

SCENARIO II: LOW NATURAL RESOURCES DAMAGE. HEAVY DAMAGE TO REMAINDER OF ECONOMY

FIGURE 7.4



SCENARIO III: SURGICAL STRIKE

In the surgical strike scenario, the energy sector is targeted for extensive damage. This scenario assumes 50% destruction of energy capital, inventory, and buildings. Ten percent of the capacity of the other natural resource sectors also is destroyed as a by-product of the attack.

This type of attack severely affects all natural resource sectors, even though much of their capacity remains intact. Post-attack, there is a drastic energy shortage. Most of the demanders of energy are intact, while the capacity to produce energy and the inventory of readily available energy commodities are halved. Imports of energy are assumed to be interrupted for five years. Thus, competition arises among consuming sectors (including the energy sector itself) for the energy output. Under these conditions, energy production is slow to recover. Only when imports resume and the supply of energy exceeds domestic output, does recovery accelerate sharply.

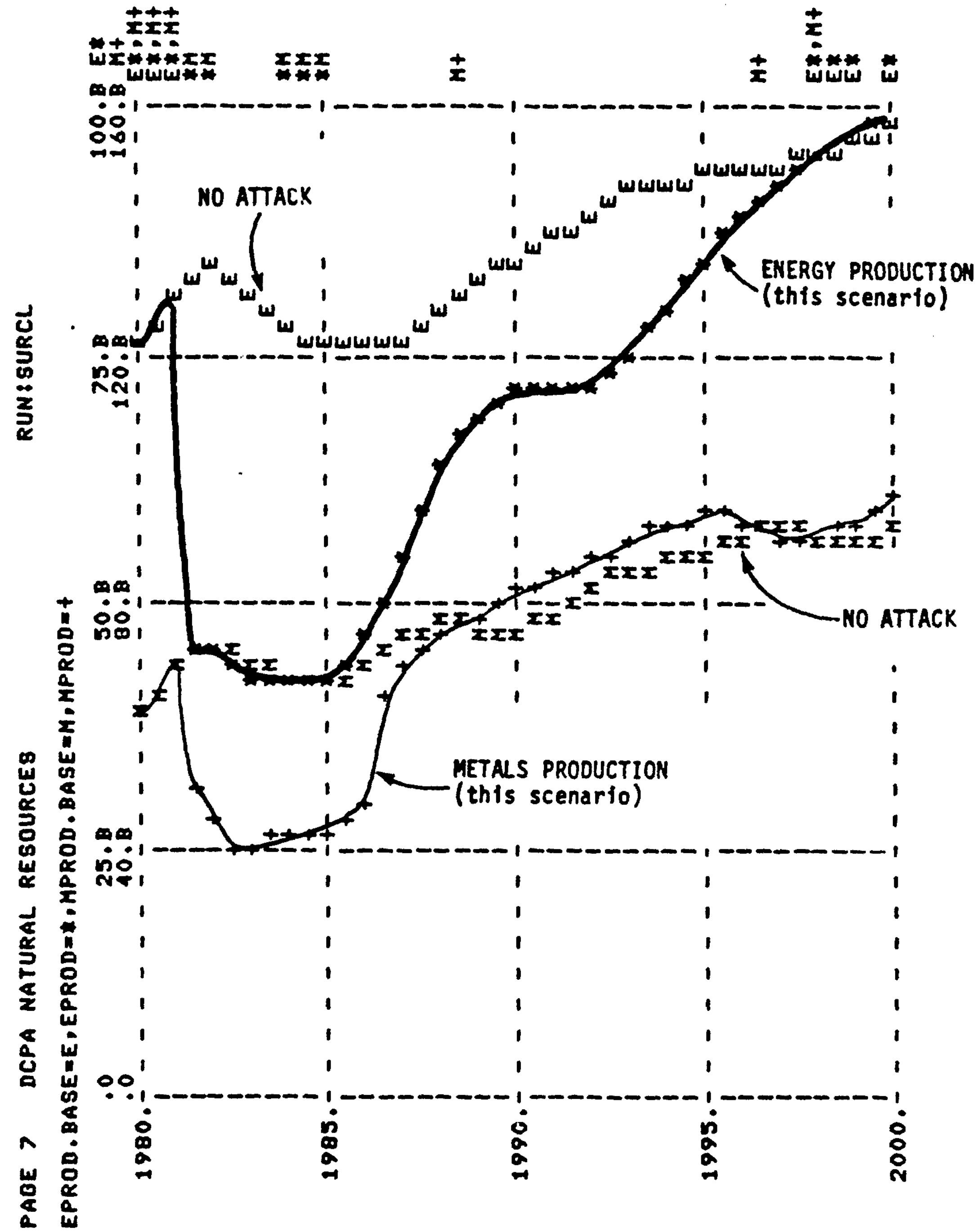
Figures 7.5 shows simulation results for the surgical strike.

SCENARIO IV. HYPERSURGICAL STRIKE

This test further demonstrates the effects of damage to the energy sector on post-attack recovery. The scenario is identical to the previous one, except that the non-energy natural resources sectors are left even more intact. Not surprisingly, the recovery problems under the two scenarios are basically similar. In Scenarios III and IV, the constraints on recovery arise directly and indirectly from inadequate energy supply. Changing the targeting so that damage to other sectors is reduced does not change these constraints.

SCENARIO III: SURGICAL STRIKE

FIGURE 7.5



The two scenarios address a serious issue of U.S. vulnerability to nuclear attack. Domestic energy production capacity, particularly for petro-fuels, tends to be concentrated in certain areas. Given the essential role of energy in economic recovery, devastating economic damage can result from relatively light physical destruction. Prolonged interruption of energy imports has a very serious adverse impact on recovery.

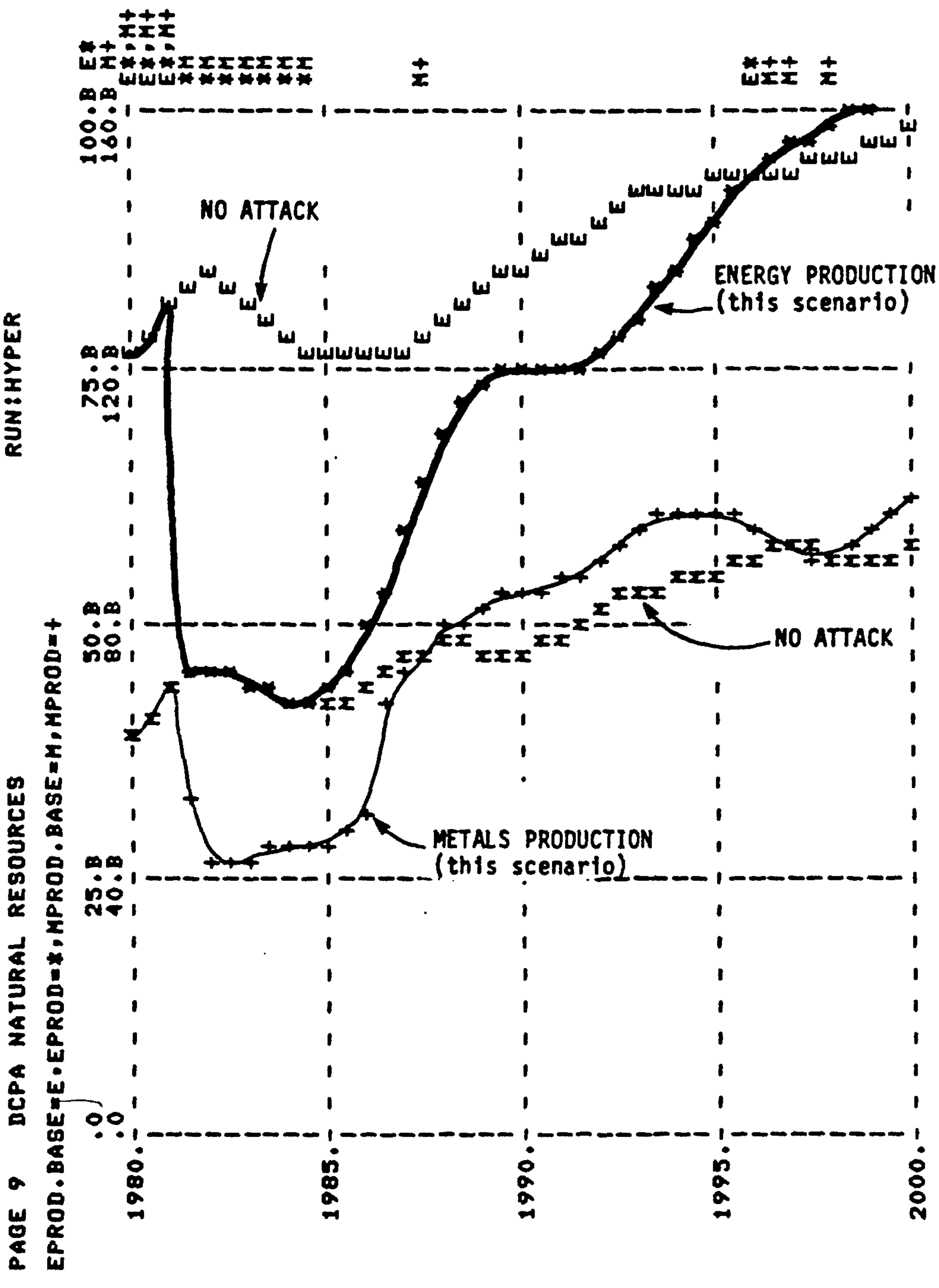
Figure 7.6 shows output for the energy sector under the hypersurgical strike scenario.

SCENARIO V: NEUTRON BOMB ATTACK

The neutron bomb attack causes economic disruption for different reasons (Figure 7.7). Here, there is very little damage to the physical capacity of the natural resource sectors. However, one-half of the sectors' labor -- and, post-attack, the ability of the sectors to acquire additional labor -- are destroyed. As a result, the production of natural resources is seriously constrained. Despite considerable automation, labor remains as crucial an element of natural resource production as capital or energy.

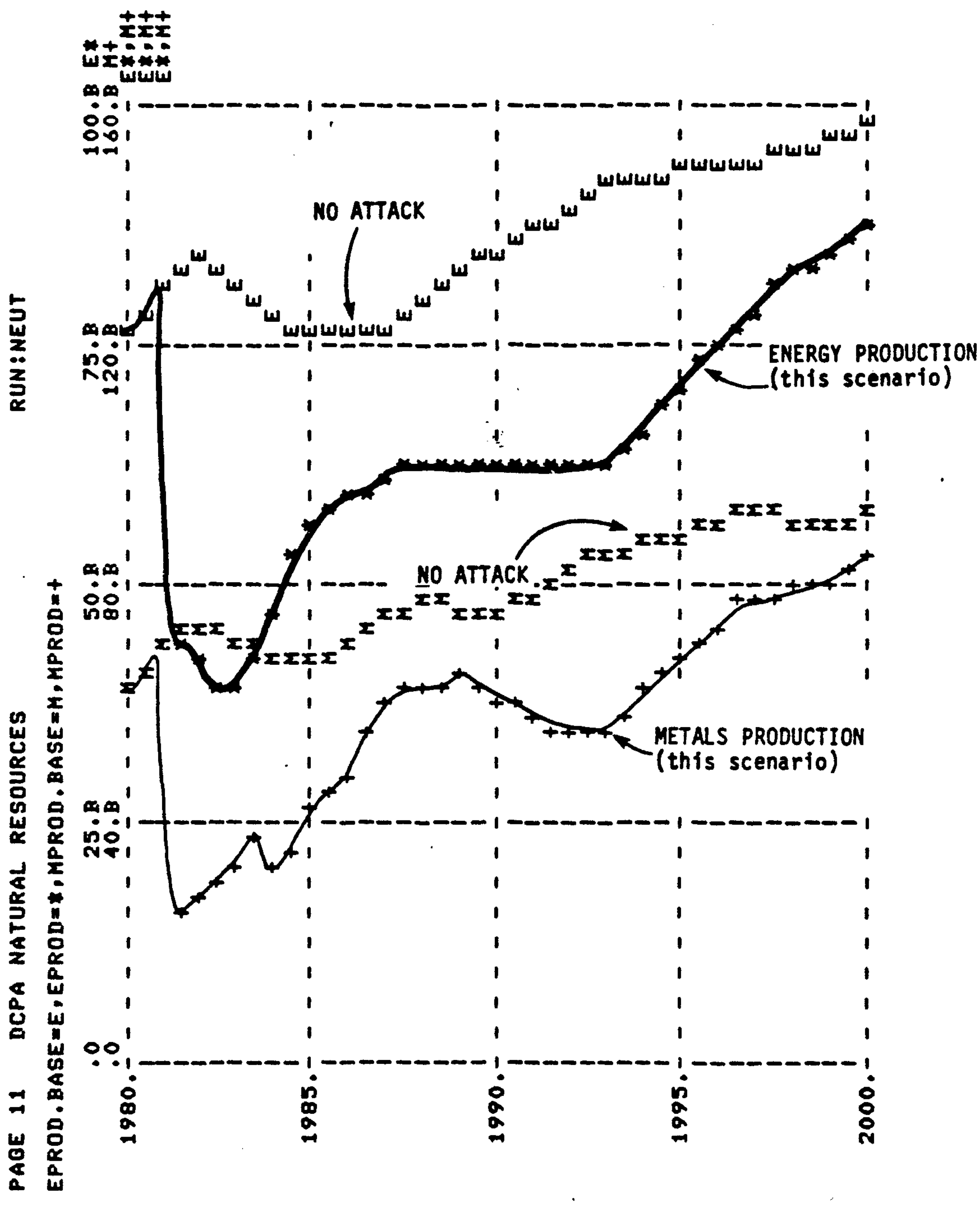
SCENARIO IV: HYPERSURGICAL STRIKE

FIGURE 7.6



SCENARIO V: NEUTRON BOMB ATTACK

FIGURE 7.7



SCENARIO VI: HEAVY DAMAGE

The results of this test indicate the importance of balance in economic recovery. While absolute recovery of natural resources production (to pre-attack levels) takes between 50% and 100% longer, the adequacy of production (i.e., output relative to demand) immediately post-attack is much better here than in the unbalanced surgical strike scenarios (Figure 7.8).

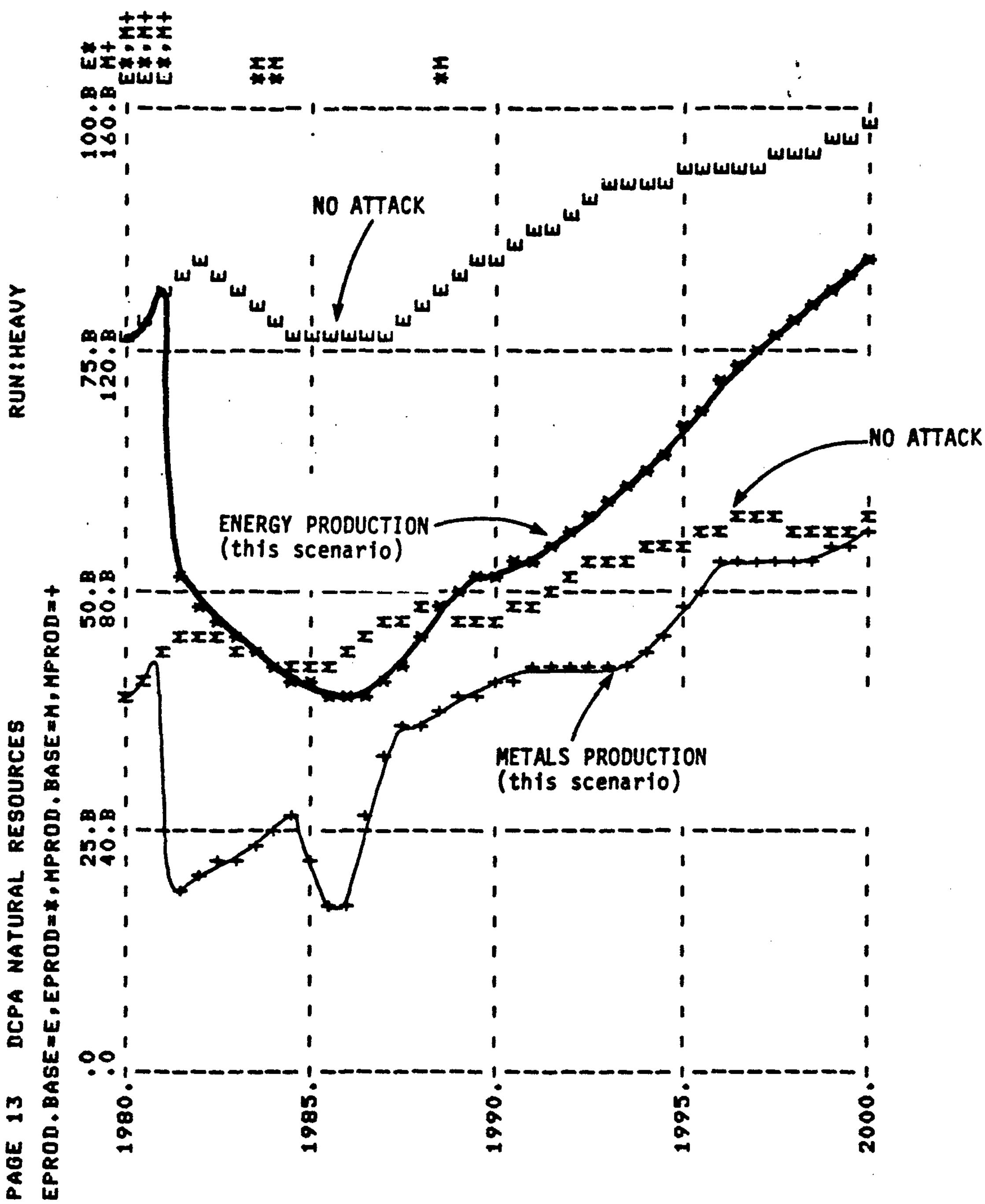
From a Civil Defense standpoint, the issue of inter-sectoral balance is crucial. The actual destruction levels of a nuclear war are difficult to foresee. Civil Defense policy must consider contigencies for all types of attacks. As the preceding scenarios indicate, different types of attacks produce very different post-attack conditions, balances, and recovery sensitivities. More severe, but more evenly-distributed damage will generally lead to faster recovery than an attack which is light overall, but which results in disproportionate destruction of one key sector. The role of Civil Defense should be to maximize conditions conducive to recovery. A range of policies aimed at that goal are discussed below.

D. Discussion of Recovery Scenarios

Many different types of recovery policy "levers" are built into the natural resources recovery model. Any lever, or combination of levers, can be used with any attack scenario. For the purpose of comparing recovery policies, it is useful to hold the attack scenario constant. Then, all variations in simulation results are because of the recovery policies specified. In this report, the surgical strike scenario (Scenario III) was

SCENARIO VI: HEAVY DAMAGE

FIGURE 7.8



chosen as the "base attack." All recovery scenarios described below incorporate the attack characteristics of Scenario III.

This scenario was chosen for three reasons. First, given the concentration of the energy sector and the clear role of energy in the U.S. economy, a surgical strike is plausible. Second, this attack scenario precipitates the crucial issues of economic recovery: financial crises, competition for scarce resources, economic imbalance, and import unavailability. Finally, it was found that Civil Defense policies have potentially dramatic effects on economic recovery under this scenario.

The recovery levers can be broadly classified into three categories. They are: stockpile-related policies; government regulation-related policies; and financial policies. Of course, the model accommodates permutations or combinations of policies within and across these categories. The results of the recovery scenarios are summarized in Table 7.9.

SCENARIO VII: RELEASE OF CURRENT STOCKS

The post-attack demands for resources are potentially overwhelming. Moreover, these demands will be for a host of different materials, not just strategic metals. The rebuilding of capital and buildings will produce requirements for huge amounts of low-technology, normally-available metals: iron, steel, copper, and aluminum. High-technology metals, such as titanium or zirconium, will surely be required, but this need will be secondary in the larger scheme of things.

Current government stockpiles of natural resources are entirely inadequate. Recovery is unchanged whether these stocks are releasd or not. In the scenario, actual 1981 stocks are released based on the supply/demand

SIMULATION RESULTS FOR ALTERNATIVE SCENARIOS

POLICY SCENARIOS

	METALS SECTOR						ENERGY SECTOR					
	TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	PRODUCTION ADEQUACY IN				LOWEST VALUE (DATE)	TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	PRODUCTION ADEQUACY IN				LOWEST VALUE (DATE)
SCENARIO		1982	1983	1984	1989			1982	1983	1984	1989	
III. Surgical Strike	6	.56	.68	.71	.91	.56 (1982)	12	.76	.72	.67	.94	.65 (1985)
VII. Release Current Stocks	6	.56	.68	.71	.91	.56 (1982)	12	.76	.72	.67	.94	.65 (1985)
VIII. Release of Hypothetical Stocks	6	.59	.72	.76	.90	.59 (1982)	12	.76	.71	.66	.89	.61 (1985)
IX. Post-Attack Stockpile Building	7	.51	.63	.65	.91	.51 (1982)	12	.74	.68	.64	.97	.62 (1985)
X. No Environmental Regulations	6	.63	.79	.77	.92	.63 (1982)	7	.75	.79	.77	.94	.74 (1985)

TABLE 7.9

SIMULATION RESULTS FOR ALTERNATIVE SCENARIOS

POLICY SCENARIOS

	METALS SECTOR						ENERGY SECTOR					
SCENARIO	TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	PRODUCTION ADEQUACY IN 1982	1983	1984	1989	LOWEST VALUE (DATE)	TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	PRODUCTION ADEQUACY IN 1982	1983	1984	1989	LOWEST VALUE (DATE)
III. Surgical Strike	6	.56	.68	.71	.91	.56 (1982)	12	.76	.72	.67	.94	.65 (1985)
XI. Wage & Price Freeze	15	.55	.57	.54	.81	.85 (1982)	16	.75	.70	.66	.82	.61 (1983)
XII. Wage Freeze & Price Limitations	6	.87	.86	.90	.94	.86	8	.85	.85	.91	.98	.85 (1982)

TABLE 7.9 (Cont.)

SIMULATION RESULTS FOR ALTERNATIVE SCENARIOS

POLICY SCENARIOS

SCENARIO	METALS SECTOR: TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	METALS SECTOR: PRODUCTION ADEQUACY IN 1982	1983	1984	1989	LOWEST VALUE (DATE)	ENERGY SECTOR: TIME TO REGAIN PRE-ATTACK PRODUCTION (YEARS)	ENERGY SECTOR: PRODUCTION ADEQUACY IN 1982	1983	1984	1989	LOWEST VALUE (DATE)
III. Surgical Strike	6	.56	.68	.71	.91	.56 (1982)	12	.76	.72	.67	.94	.65 (1985)
XIII. Subsidies and Borrowing	6	.56	.69	.69	.93	.56 (1982)	5	.76	.70	.67	1.00	.70 (1983)
XIV. Taxation	6	.56	.68	.71	.93	.56 (1982)	7	.76	.71	.67	.98	.66 (1985)
XV. Combination of Scenarios XIII & XIV	5	.56	.69	.69	.94	.56 (1982)	5	.76	.70	.67	.97	.67 (1984)
XVI. Combination of Scenarios XII, XIII, XIV	6	.87	.84	.95	.95	.84 (1983)	7	.85	.85	1.01	.98	.85 (1982)
XVII. Combination of Scenarios X, XII, XIII, XIV	6	.84	.96	.92	.95	.84 (1982)	7	.88	1.04	1.04	.98	.88 (1982)

TABLE 7.9 (Cont.)

balance: as demand exceeds supply by a greater margin, a higher fraction of the existing stockpiles are released. Although most of the stocks are released over the five years post-attack (a total of over three billion 1970 dollars of material), recovery is not significantly affected.

SCENARIO VIII: RELEASE HYPOTHETICAL STOCKS

Although current stocks are inadequate, stockpiles can importantly aid recovery. This scenario assumes that government stockpiles of energy and metals equal about 50% of the pre-attack annual consumption which existed at attack time.

The total time required for the resource sectors to regain pre-attack production is not shortened by this policy. Nevertheless, the policy is quite beneficial. Table 7.10 shows the differences between this scenario and the base attack for metals for price and imports. Both post-attack price and imports are substantially lower in this stockpile-release case, a desirable outcome.

In one sense, government stockpiles can be regarded much like imports: an available source of supply, obtainable without current domestic production. Of course, imports are less secure in time of war; this difference is reflected in the model equations. By relying on government stocks, resource sectors can ship more goods, rebuilding capacity with the extra revenues and supporting the recovery of consumer sectors.

These and other simulations demonstrate an additional aspect of stockpile release policy. The earlier stocks are released, the more impact they have in aiding recovery. Particularly if resource imports are interrupted, post-attack "pump priming" is the best use of stockpiles.

COMPARISON OF PRICE AND IMPORTS FOR THE METALS SECTOR

Year	PRICE ($/ton) III. Base Attack	PRICE ($/ton) VIII. Release Hypothetical Stocks	IMPORTS (Billions 1970 $/yr) III. Base Attack	IMPORTS (Billions 1970 $/yr) VIII. Release Hypothetical Stocks
1981	357.3	357.3	10.71	10.71
1982	657.6	580.6	0.25	0.25
1983	1124.0	703.6	12.94	11.47
1984	1172.0	837.3	13.53	12.60
1985	1483.0	1061.0	14.47	12.92
1986	1842.0	1387.0	14.98	14.02
1987	1629.0	1426.0	15.81	15.36

TABLE 7.10

SCENARIO IX: POST-ATTACK STOCKPILE BUILDING

One can envision a post-attack environment where the Civil Defense emphasis is not directed toward recovery per se, but instead directed toward preparing the population and economy for another attack. This scenario tests the policy of attempting to build, post-attack, large government stockpiles of natural resources.

The policy substantially worsens the recovery capability of the economy (Figure 7.11). Post-attack, there are severe imbalances of supply and demand. Building stockpiles significantly worsens the imbalance between natural resource production and demands. Prices are even higher, as the result of competition for scarce resources.

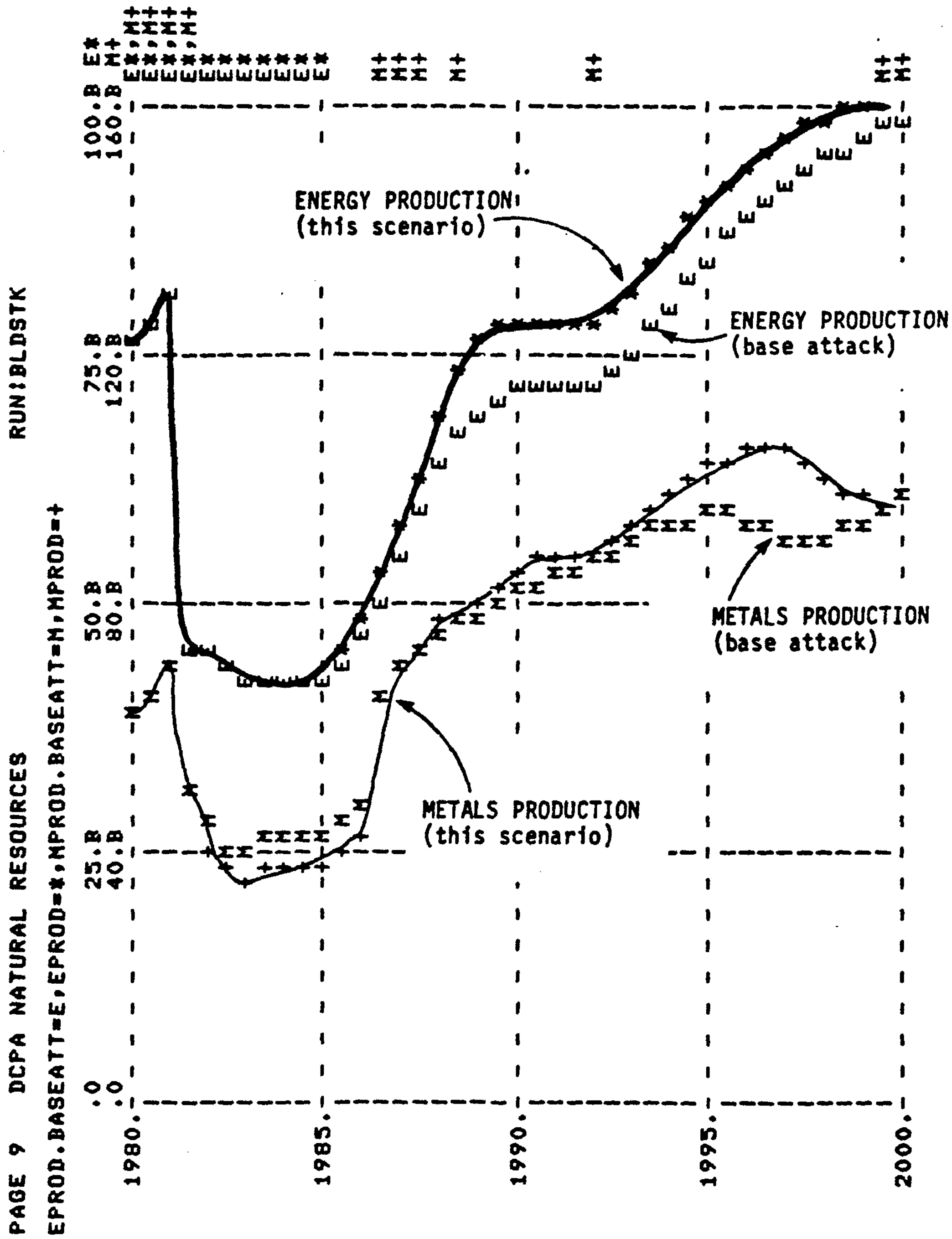
Of course, this scenario assumes a single attack. Model users may want to explore the trade-offs between most efficient recovery from one attack and the policies which do best under multi-attack scenarios.

SCENARIO X: NO ENVIRONMENTAL REGULATIONS

Each model assumption is formulated so that if no attacks were to occur, reasonable forecasts to sectoral economic behavior over the next twenty years could be obtained. Some of these assumptions could be changed in a post-attack environment. Compliance with environmental regulations, for example, is a source of tremendous cost to resource producers. Post-attack, these regulations may well be suspended to lessen the financial strains on key sectors and maximize production capacity utilization. Figure 7.12 and Table 7.13 illustrate the results of completely lifting all environmental regulations beginning one year post-attack.

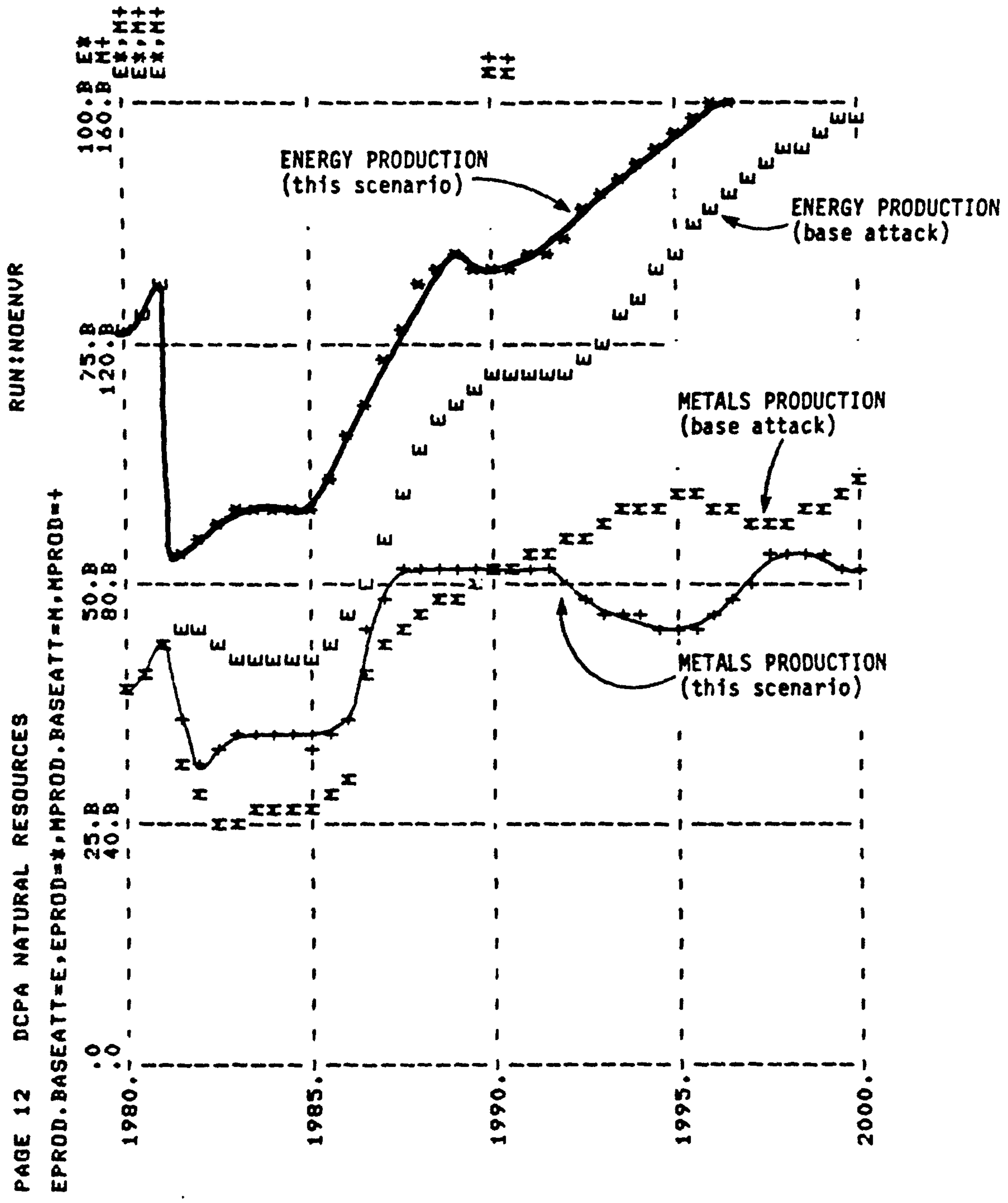
SCENARIO IX: POST-ATTACK STOCKPILE BUILDING

FIGURE 7.11



SCENARIO X: NO ENVIRONMENTAL REGULATIONS

FIGURE 7.12



DESIRED CAPITAL INVESTMENT IN THE ENERGY SECTOR
(BILLION 1970 $ PER YEAR)

Year	III. Base Attack	X. No Environmental Regulations	Percentage Change
1981	280.4	280.4	0
1982	361.1	251.4	-30
1983	404.2	257.9	-36
1984	387.8	262.6	-32
1985	394.8	259.1	-34
1986	379.2	252.1	-34
1987	342.6	229.1	-33
1988	305.1	197.7	-35
1989	258.8	151.0	-42

TABLE 7.13

Suspending environmental regulations dramatically aids recovery. The energy sector regains pre-attack production rates much more quickly. Increased energy availability stimulates the recovery of other sectors. The reason is that post-attack requirements for capital investment in the energy sector average 30% lower in this scenario than in the base attack.

High inflation, low production, and insufficient cash flow to undertake needed capital investment all characterize a post-attack environment. Inflation and depressed revenues (because of insufficient production and shipments) constrain each sector's ability to repair, upgrade, and expand its capital equipment. This combination of factors inhibits recovery. Suspending environmental regulations helps to circumvent these particular problems by increasing the efficiency of capital investment. That is, a dollar of investment buys more real production capacity. Increased capacity means more shipments and greater cash flow, which allows still more capital investment.

This scenario does not reflect the trade-offs between accelerated economic recovery and the long-term consequences of relaxed environmental regulations. Examining questions of environmental quality is beyond the scope of the natural resources model. However, such trade-offs are important and require analysis.

SCENARIO XI: PRICE AND WAGE FREEZE

SCENARIO XII: PRICE AND WAGE LIMITATIONS

These two scenarios illustrate variations of an obvious post-attack policy: wage and price control. Such policies would be invoked in an attempt to limit general financial panic and extreme inflation.

The results of the simulations indicate such controls are potentially detrimental to recovery. A freeze that holds prices at their pre-attack levels so limits revenues that, for example, metals production is only 40% of its base attack value five years after attack time (the point at which the price freeze ends). (See Table 7.14.)

However, price controls can be beneficial, if used correctly. In Scenario XII, prices are set higher than the pre-attack values, but lower than the levels obtained in simulations with no price control. This policy provides the natural resource sectors with needed cash flow, while simultaneously limiting inflation and costs. The result is a 36% increase in metals production in 1986 over the base attack, and a 231% increase over the price-freeze run. Figures 7.15 and 7.16 compare these scenarios to the base attack.

SCENARIO XIII: FINANCIAL CONSIDERATIONS -- SUBSIDIES AND BORROWING

The remaining scenarios describe individual and combinations of financial policies aimed at alleviating the post-attack cash flow crisis. This crisis is caused by high inflation, high energy costs, very large capital investment requirements, but lowered revenues because of depressed production, unavailability of transport to ship goods, and inventory shortages.

Most of the financial policies tested have a beneficial effect on recovery. It is important to realize, however, that no policy is free. Each scenario has apparent benefits and associated costs. An income tax reduction policy, for example, would aid recovery by allowing sectors to retain more cash flow for investments. However, this reduces government revenues and, hence, government's ability to provide recovery services or

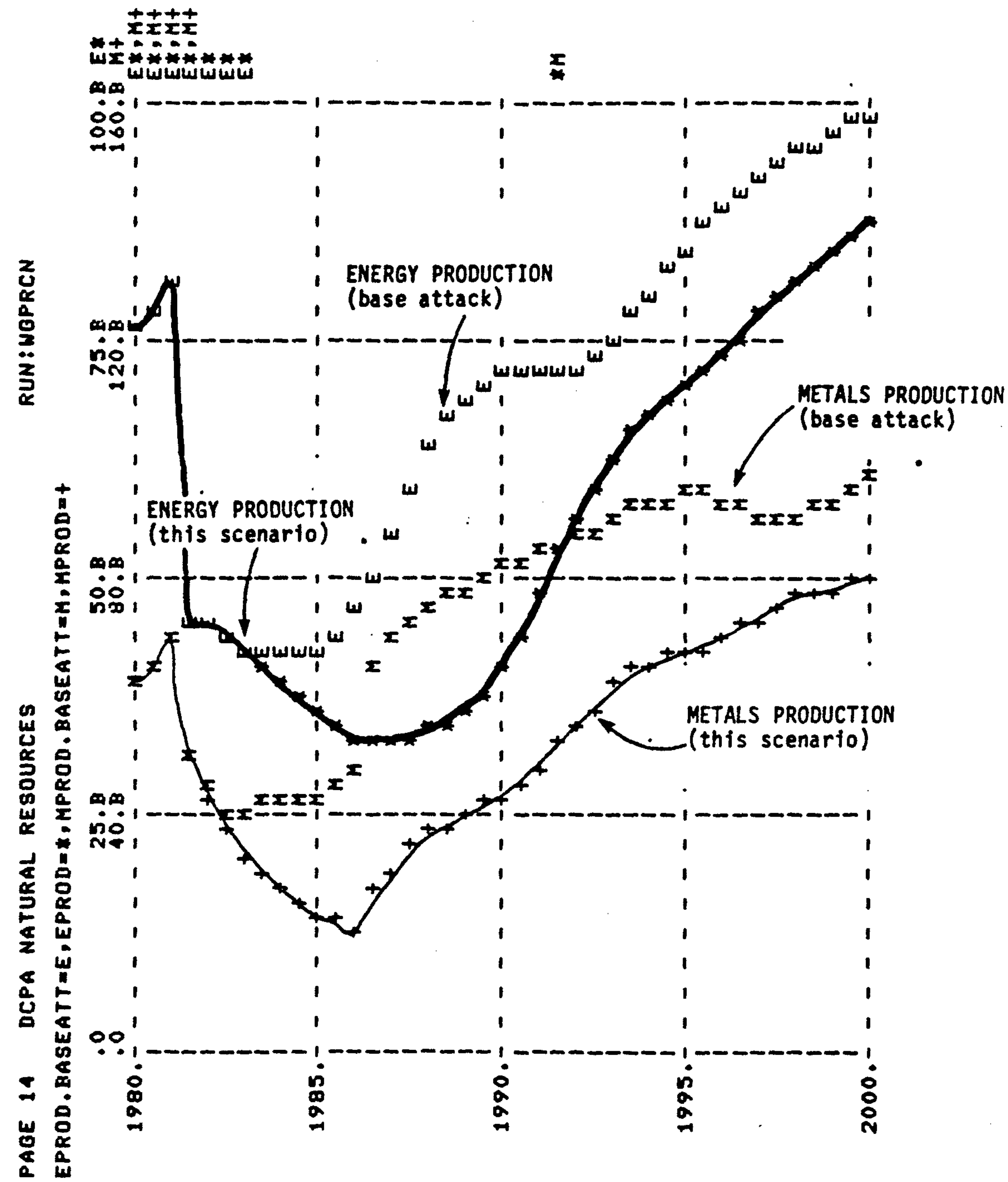
PRODUCTION AND DESIRED CAPITAL IN THE METALS SECTOR

Year	Production (Billion 1970 $) III. Base Attack	XI. Price Freeze	XII. Price Limitations	Desired Capital (Billion 1970 $) III. Base Attack	XI. Price Freeze	XII. Price Limitations
1981	70.1	70.1	70.1	11.7	11.7	11.7
1982	44.0	43.4	60.3	21.3	20.9	21.4
1983	40.1	33.7	50.4	18.9	18.2	13.8
1984	43.2	28.5	53.7	15.4	17.7	8.9
1985	43.0	23.7	59.6	13.6	17.8	6.1
1986	46.4	19.1	63.3	13.2	18.6	6.1
1987	69.1	31.0	68.0	11.4	21.4	7.8
1988	75.5	36.4	75.6	10.6	17.6	8.9
1989	78.5	39.5	81.9	9.3	15.8	9.3

TABLE 7.14

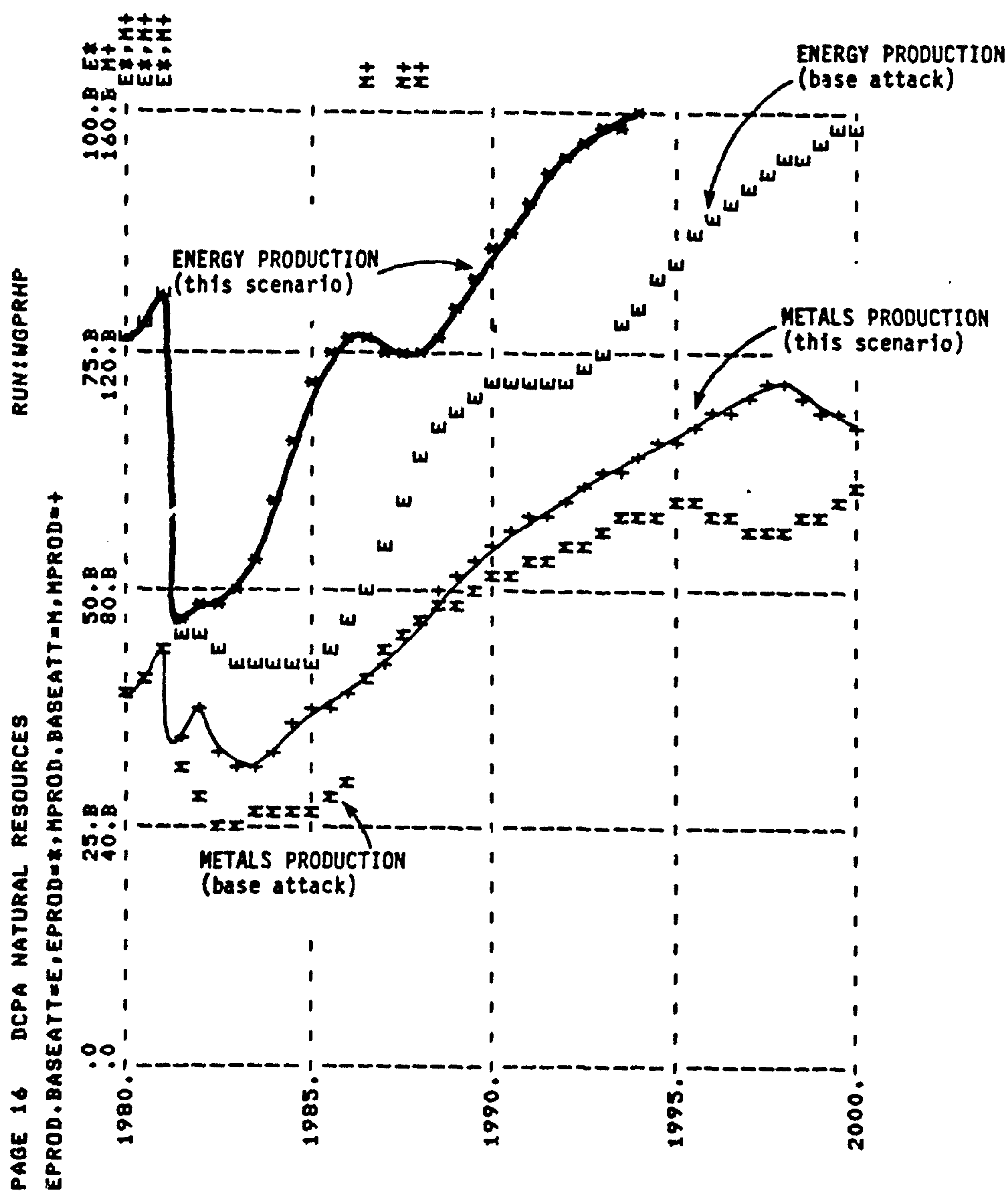
SCENARIO XI: WAGE AND PRICE FREEZE

FIGURE 7.15



SCENARIO XII: WAGE FREEZE AND PRICE LIMITATIONS

FIGURE 7.16



to engage in a military build-up. This trade-off can be addressed with the full U.S. Economic Recovery Model.

The first financial policy tested is a combination of government subsidies to each resource sector, and an increase in the maximum debt/equity rates allowed by commercial lenders as a result of government debt guarantees. This scenario results in much quicker recovery, particularly in the energy sector (Figure 7.17). Subsidies increase sector equity. That, plus allowing more borrowing per unit of equity, increases the sectors' short-term cash flow substantially.

SCENARIO XIV: FINANCIAL CONSIDERATIONS -- TAXATION

This scenario also proved beneficial (Figure 7.18). Diversion of cash flow from tax payments to capital investment allowed a much faster build-up of production.

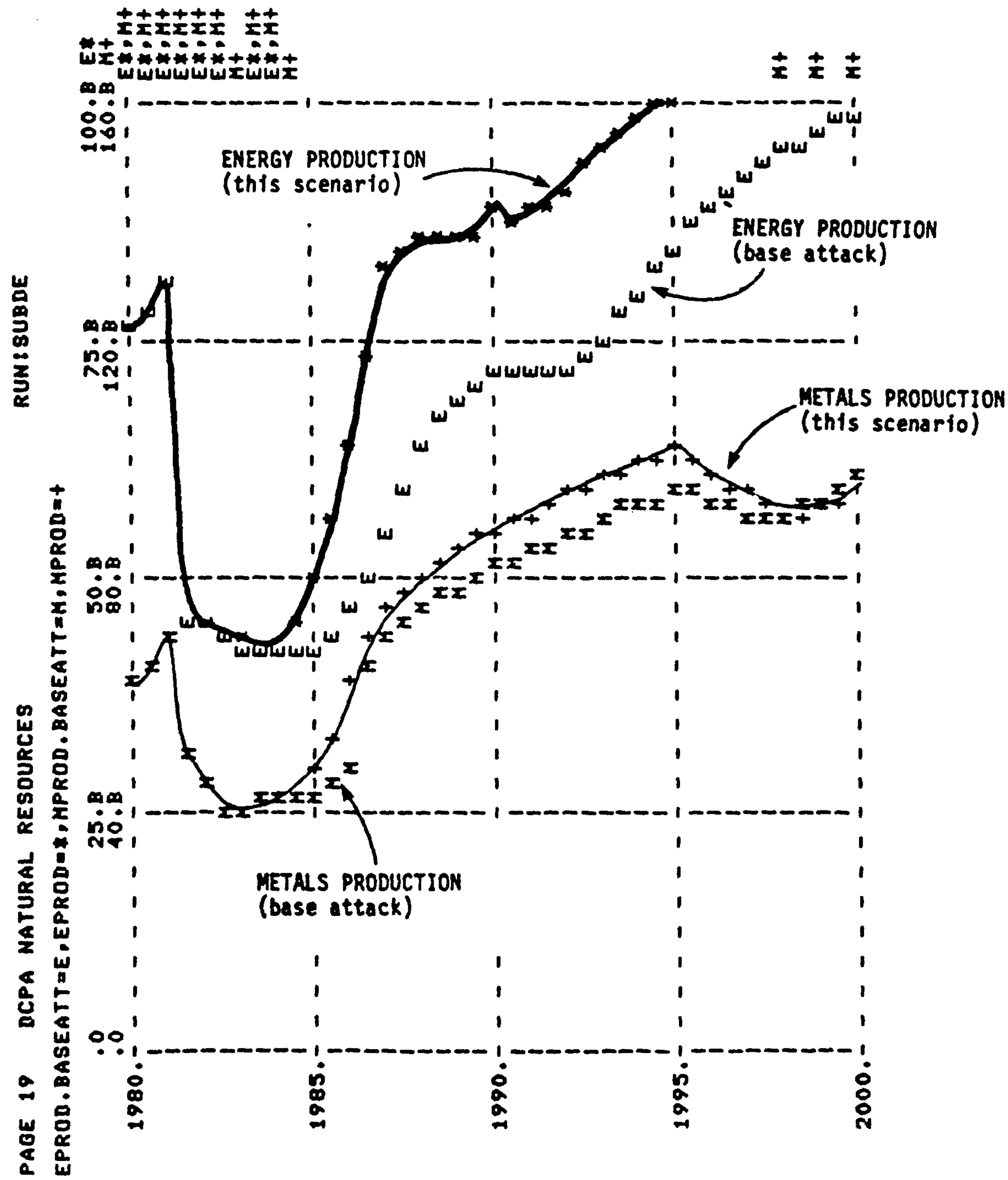
E. Combinations of Policies

Combining policies in an effort to avoid a post-attack financial crisis is an obvious possibility. However, it is important to select such policies cohesively and prudently. Certain policies are redundant; others do little to alleviate the most pressing constraints on recovery.

Scenario XV, a combination of income tax relief, subsidies, and government loan guarantees, provides the quickest recovery of natural resource production (Figure 7.19). Even so, resource supplies and demands are not balanced before imports resume. Adding price and wage limitations (Scenario XVI, Figure 7.20) significantly improves production adequacy in

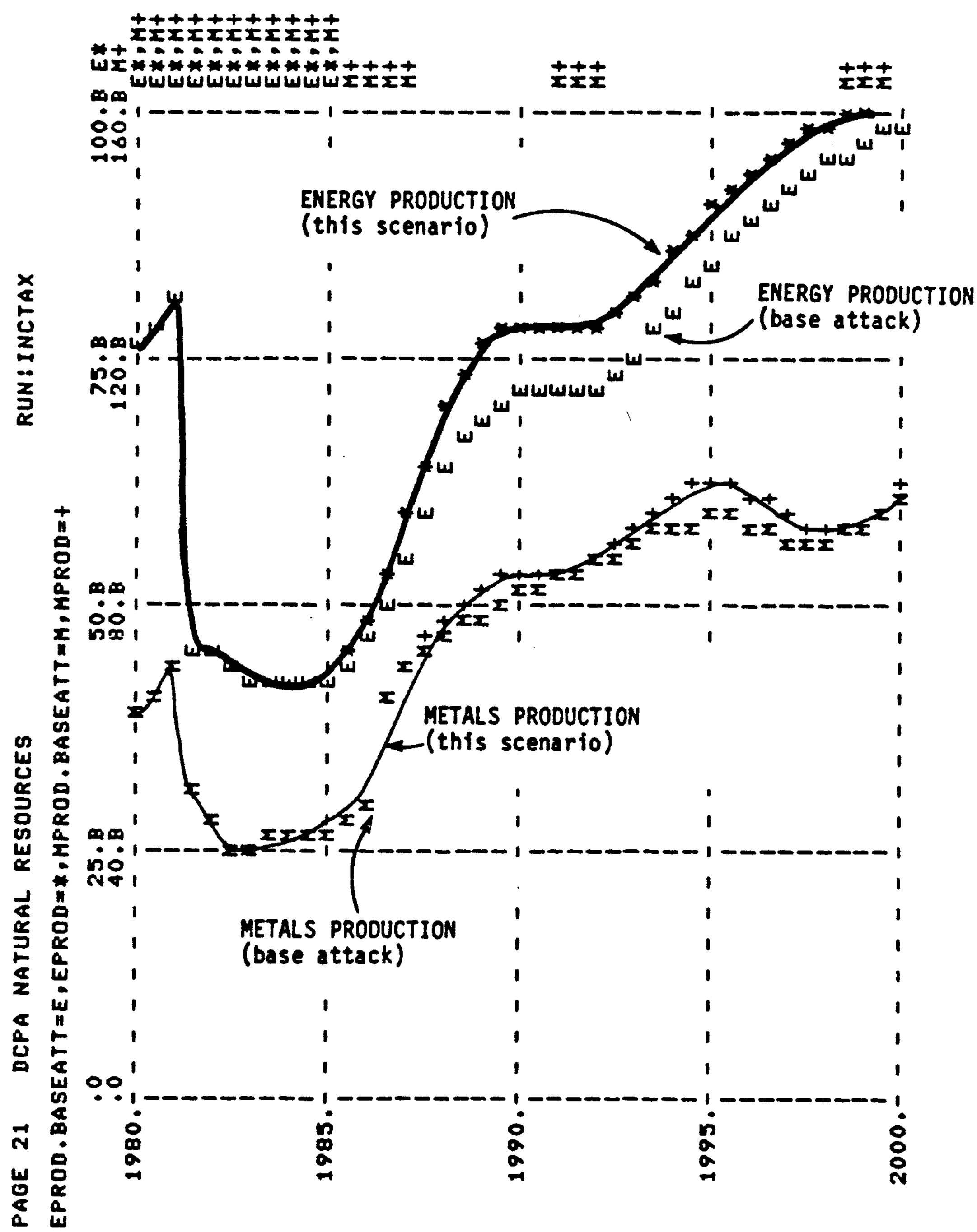
SCENARIO XIII: FINANCIAL CONSIDERATIONS -- SUBSIDIES AND BORROWING

FIGURE 7.17



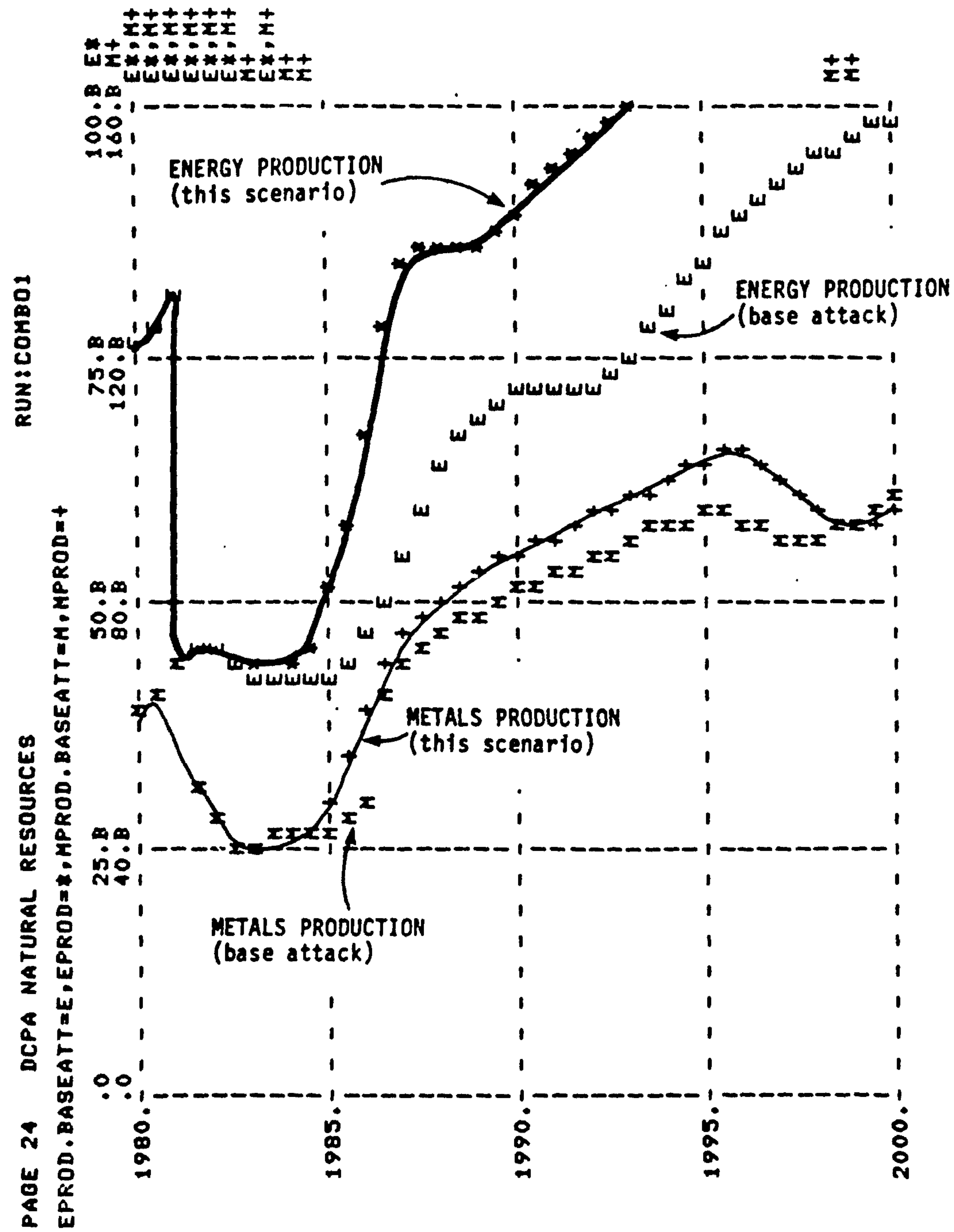
SCENARIO XIV: FINANCIAL CONSIDERATIONS -- TAXATION

FIGURE 7.18



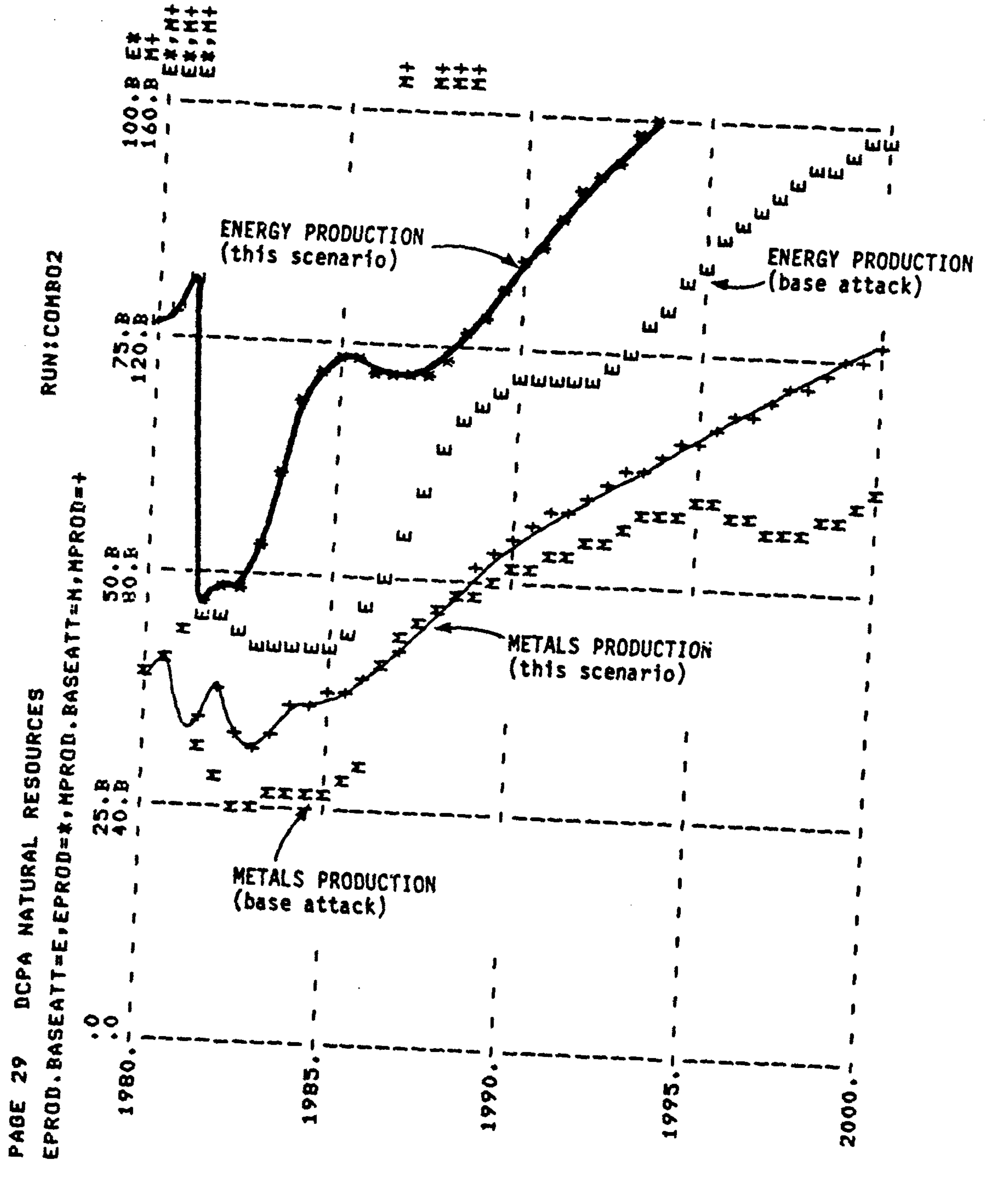
SCENARIO XV: COMBINATION OF SCENARIOS XIII & XIV

FIGURE 7.19



SCENARIO XVI: COMBINATION OF SCENARIOS XII, XIII, & XIV

FIGURE 7.20

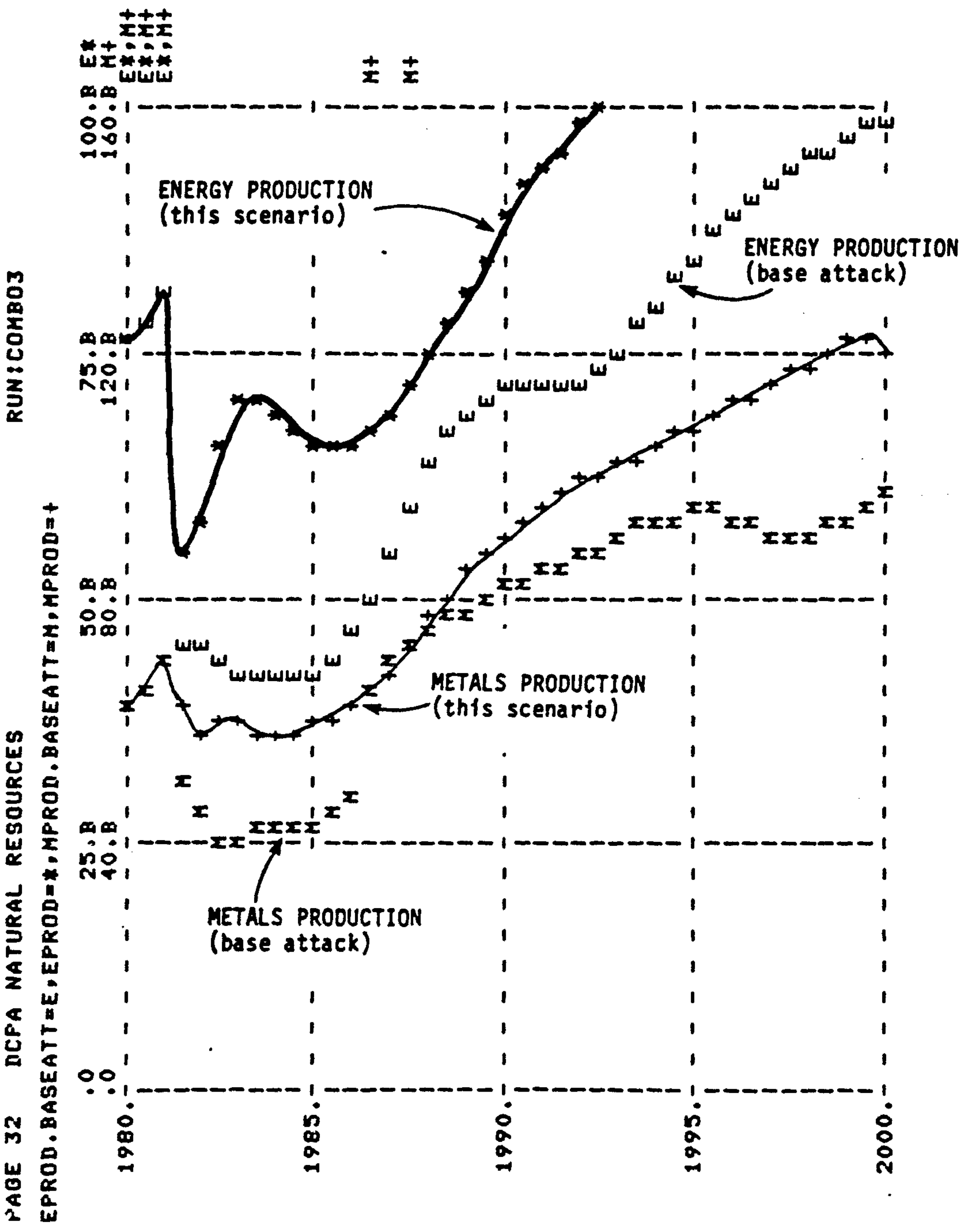


the first few years post-attack, though attainment of pre-attack production levels is actually delayed slightly.

Scenario XVII, which combines the previous scenario with the relaxation of environmental regulations, shows even faster recovery in the years immediately following the attack (Figure 7.21). Increased efficiency of capital investment coupled with massive financial assistance causes the energy sector to meet demand within two years post-attack. The magnitude of destruction is identical to earlier scenarios. The impact of recovery policies, when used intelligently and prudently, can be dramatic.

SCENARIO XVII: COMBINATION OF SCENARIOS X, XII, XIII, & XIV

FIGURE 7.21



VIII. CONCLUSIONS

This chapter summarizes the general conclusions which can be drawn from the various attack scenarios and recovery policies tested with the natural resources model. The key factors affecting economic recovery are shown in Figure 8.1.

Perhaps the most conspicuous, recurring impediment to recovery illuminated by the model is the post-attack cash flow crisis. In the aftermath of a nuclear attack, the natural resource sectors of the U.S. economy will have to undertake massive capital investment programs to rebuild. Clearly, the magnitude of required investment depends on the damage suffered and on the level and recovery rate of resource demands. Nevertheless, under a wide range of attack scenarios, this is the major recovery problem.

The funds available for capital investment are, essentially, from three sources: internal cash flow (i.e., retained earnings plus depreciation), net new borrowing, and government subsidies. The crisis occurs because the investment needs are large, and the internal cash flow of the resource sectors is constrained by:

1. the effects of very high inflation on production costs;
2. the effects of insufficient production capacity on shipments and, hence, on sector revenues;
3. the effect of transportation shortages on shipments and revenues; and
4. the effect of insufficient energy production on energy prices and the costs of energy-consuming sectors.

The debt available to the resource sectors, limited by commercial debt/equity criteria, is not sufficient to make up the difference. In

KEY FACTORS AFFECTING RECOVERY

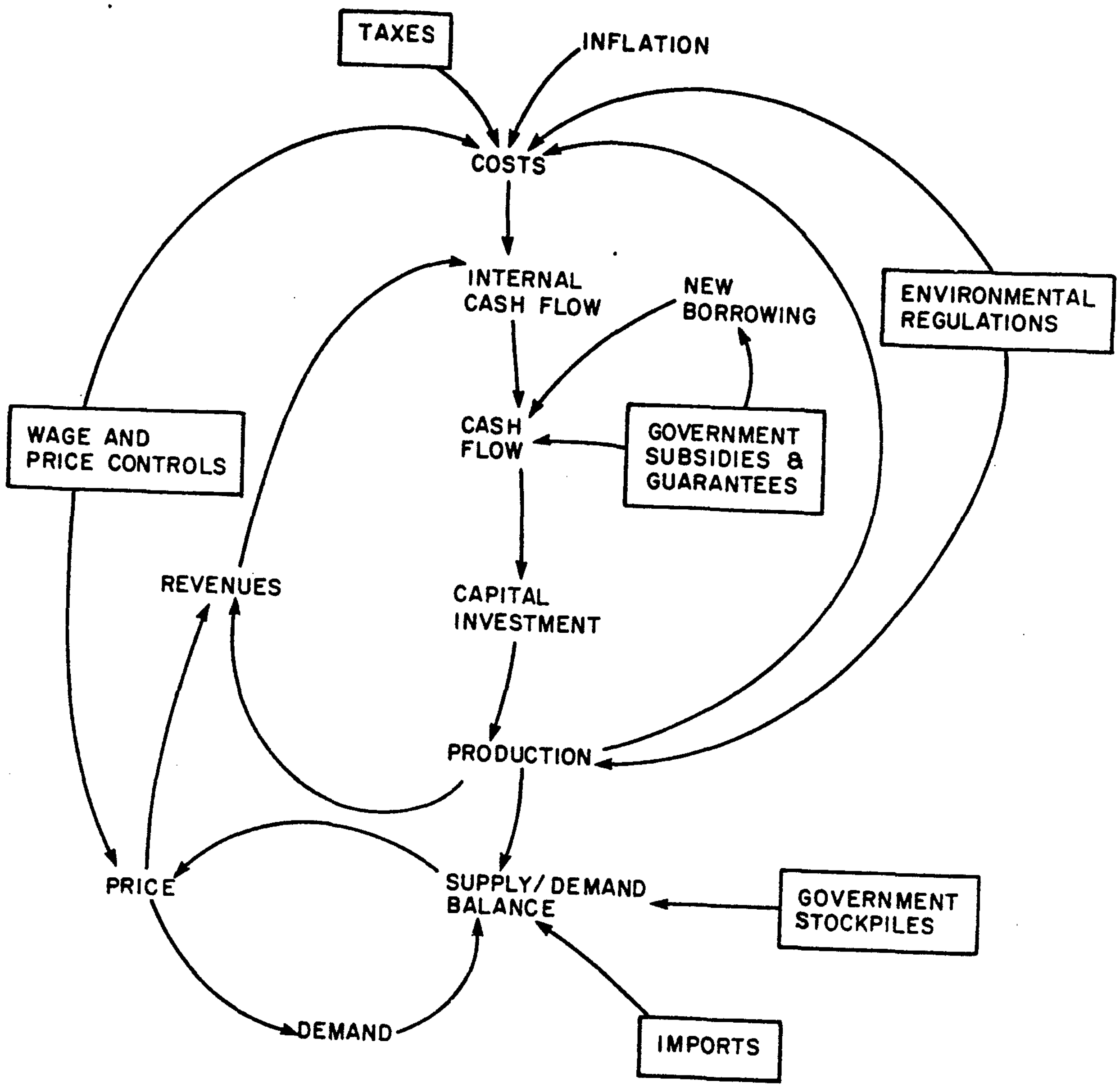


FIGURE 8.1

essence, the situation is a classic "Catch 22." More production capacity would generate more revenues and pay for itself in a short time, but the resource sectors do not have enough funds to acquire the capacity.

Policies which break this financial logjam have a very large effect on post-attack recovery. Internal cash flow is augmented by moderate price controls and tax reductions. With controls, there is a delicate balance between reducing a sector's costs and reducing its revenues. Too much of the latter is no good. Government subsidies add funds and, because they also increase sectoral equity, they facilitate more commercial borrowing. Government-guaranteed loans allow the sectors' borrowing to exceed normal commerical debt/equity limits.

The cash flow crisis is very sensitive to both general inflation and energy prices. Government policies which reduce inflation greatly enhance the recovery of the natural resource sectors. There are three ways to attack high energy prices: price controls, government stockpile releases, and resumption of imports. The first is very dangerous because it can worsen the energy shortage and constrain the output of major energy-consuming sectors.

Government stockpiles are most effectively used in a "pump-priming" role. They have to be released rapidly during the first year or two post-attack, but once again, a delicate balancing act is required. If resource prices are depressed too much by stockpile releases, the cash flow crisis is worsened and recovery slowed. The highest-priority resources to stockpile for "pump priming" are fuels and basic metals such as iron, steel, copper, and aluminum. The esoteric metals are of secondary importance in economic recovery, though critical for a military build-up.

The resumption of natural resource imports, particularly fuels, is very beneficial to recovery. Energy imports reduce consumer costs and facilitate full capacity utilization, which is not possible under many scenarios because of energy shortages.

The energy sector is the keystone in the whole system, and absolutely critical to economic recovery. The energy sector is the single largest consumer of its own outputs (e.g., fuel is required for electric power generation). If the energy sector does not give itself top priority, the self-reenforcing recovery dynamics cannot build up momentum. It takes energy to make energy, and if the energy sector cannot get enough of its own outputs, it is constrained and -- importantly -- so are all of the other major energy consuming sectors. Furthermore, the energy sector is very dependent upon transportation and distribution. For all of these reasons, the energy sector is also our "Achilles heel." The natural resources model shows very clearly what many people fear: a hyper-surgical strike against the energy sector would bring the U.S. economy to its knees for a period of years, in the absence of a large government fuel stockpile or massive energy imports.

The results of the attack scenarios and policy tests confirm the key finding from earlier simulations with the overall U.S. Economic Recovery Model: recovery following a nuclear attack requires reestablishing and maintaining dynamic <u>balance</u> among the interdependent sectors of the economy. Persisting physical imbalances between production and demand cascades into further constraints and imbalances, stimulates worsening inflation, and fuels the cash flow crisis which ultimately bogs down recovery. Under a wide range of attack scenarios, the natural resource

sectors will be sources of dangerous imbalances, and will constrain recovery of the overall U.S. economy. Civil Defense policies such as the ones described above can reduce these imbalances and thus merit serious consideration.

FOOTNOTES

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[2]J.W. Forrester, Industrial Dynamics (Cambridge: MIT Press, 1961), E.B. Roberts, ed., Managerial Applications of System Dynamics (Cambridge: MIT Press, 1978), and J.M. Lyneis, Corporate Planning and Policy Design (Cambridge: MIT Press, 1980).

[3]A.L. Pugh, III, DYNAMO User's Manual, 5th edition, Cambridge, MIT Press, 1977.

[4]U.S. Department of Commerce, Bureau of Economic Analysis, "Input-Output Structure of the U.S. Economy: 1967," Survey of Current Business, September, 1974.

[5]Ibid.

[6]Peterson, op. cit.

Chapter IV

[1]Ibid.

[2]Pugh, op. cit.

[3]U.S. Department of Commerce, op. cit.

[4]Ibid.

[5]Ibid.

[6]In the model, the amount of resources in the ground was derived using the definition of the U.S. Department of Interior, Bureau of Mines, found in Mineral Facts and Problems, 1975 Edition, Washington: Government Printing Office, 1976, pp. 16-17.

[7]For a complete listing of what is included under the heading "capital goods," see Peterson, op. cit., Appendix A.

[8]U.S. Department of Commerce, Bureau of the Census. Statistical Abstract of the United States: 1979 (Washington: Government Printing Office, 1979).

[9]U.S. Department of Interior, op. cit.

[10]U.S. Department of Treasury, Internal Revenue Service, Corporation Income Tax Returns, 1965 (Washington: Government Printing Office, 1966).

[11]U.S. Department of Labor, Bureau of Labor Statistics, Wholesale Prices and Price Indexes (Washington: Government Printing Office, 1966).

[12]U.S. Department of Commerce, Bureau of Economic Analysis, op. cit.

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[14]U.S. Department of Interior, op. cit.

[15]U.S. Federal Emergency Management Agency, Stockpile Report to Congress (Washington: Government Printing Office, 1980), and U.S. Department of Interior, op. cit.

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[17]U.S. Department of Interior, op. cit.

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[20]U.S. Department of Commerce, Bureau of Economic Analysis, The National Income and Product Accounts of the United States 1929-1974 (Washington: Government Printing Office, 1976).

[21]U.S. Department of Treasury, op. cit.

[22]Ibid., and U.S. Department of Commerce, Bureau of the Census, National Income and Product Accounts, op. cit.

[23]U.S. Department of Commerce, Bureau of Economic Analysis, Input-Output Study, op. cit.

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[1]Ibid.

[2]U.S. Department of Treasury, op. cit.

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APPENDIX

Annotated List of Policies and Scenarios

The computer simulation model described in this report is a highly capable planning tool designed for strategic analysts who evaluate economic recovery of t ıe United States economy following a nuclear attack. Much of the model's analytic capability stems from the extensive number of policies and attack scenarios which the model can support. This appendix describes the range of policies that the model is designed to address, as well as the model parameters used to implement those policies.

The policies and model parameters described herein are not necessarily identical to their counterparts in the full-scale U.S. recovery model (described in our November 1980 Final Report: Development of a Dynamic Model to Evaluate Economic Recovery Following a Nuclear Attack). All of the parameters herein correspond to those policy levers in the natural resources model which are contained in this report.

This appendix is divided into three sections. The first describes attack scenarios; the second, potential recovery scenarios; the third and final section is a computer-generated run stream of the inputs to the model which produced the attack and recovery scenarios described in this report.

Attack Scenarios

The model can represent a wide variety of attack scenarios through careful selection of values for certain variables. For each attack, the measures of destruction in each natural resource sector can be specified. Thus, such scenarios as sector specific damage, component damage timing, and the state of the economy at attack time, can all be dictated by the user.

Figure A-1 lists some of the attack components that may be investigated using the model. The particular model variable name also is given.

FIGURE A-1

PARTIAL LISTING OF ATTACK COMPONENTS

ATTACK COMPONENT	VARIABLE	COMMENT
Capital Destroyed	ZFC	natural resource sectors only
Availability of Capital	ZAPECC	surrogate for destruction of capital manufacture in remainder of the economy; user-specified if ZISC=1
Availability of Capital	ZARTC	average recovery time for capital availability
Labor Destroyed	ZFL	in natural resources sectors only
Availability of Labor	ZAPELC	surrogate for availability of labor in remainder of economy, user-specified if ZISL=1
Buildings Destroyed	ZFB	in natural resources sector only
Availability of Buildings	ZAPEBC	surrogate for availability of new construction post-attack
Availability of Buildings	ZARTB	average recovery time for new construction
Inventory Destroyed	ZFI	in natural resources sectors only
Demand	ZAPED	main surrogate for initial destruction in remainder of economy
Demand Recovery	ZARTD	average recovery time for demand

FIGURE A-1 (continued)

Transportation	ZECTT, ZEDTT	these tables define the assumptions about what fraction of transportation is lost based on total economic destruction (defaults based on adequacy of capital and destruction of economy)
Imports	ZIMPUN	what length of time imports are interrupted in each natural resources sector
Import Stop Time	ZISTIM	when imports are cut off (default: time of attack)
Attack Time	ZATIME	time of attack
Stockpiles Destroyed	ZSTOCK	fraction of natural resources stockpiles destroyed at attack time
Resources Destroyed	ZRSR	fraction of resources remaining in-ground destroyed (simulated target of material-rich areas, e.g., oil fields)
Resources Contaminated	ZCONT, ZCONTL	fraction of resources rendered temporarily unavailable due to post-attack radiation
Capital Dependency	ZCEDEP	measures dependency of surviving capital equipment on destroyed equipment

Recovery Policies

The model can investigate many pre-attack and recovery policies. Recovery policies may be attempted in any combination or permutation with other recovery policies or with different attack assumptions. Thus, there are virtually a limitless number of scenarios that the user may investigate.

Many recovery policies can be simulated by altering attack scenarios. For example, a recovery policy that concentrated much of our post-attack political and economic energy on resumption of interrupted imports would be simulated as a change in the attack parameter which governs how long imports are assumed to be shut off.

Figure A-2 lists the many recovery policies that the model can investigate. Where applicable, the model variable used to simulate a particular policy is listed.

FIGURE A-2

RECOVERY POLICIES

POLICY	COMMENT
Resource Allocation	Resources are allocated based on demand and priority of each sector. The altering of priorities is the primary process by which the government can initiate a centrally-planned recovery process. The variables in question are: ADPRN, BDPRN, CDPRN, D1DPRN, D2DPRN, GDPRN, M1DPRN, M2DPRN, RDPRN, SDPRN, TDPRN, UDPRN, and GSDPRN.
Post-Attack Wage & Price Freeze	Wages and prices can be frozen by setting PRCNLN to a certain number of years. CIPERT must be modulated as well, to reflect the slowing of inflation which results from the freeze. PRCSW must be set to 0.
Wage & Price Control	Prices can be set to rise up to, but not beyond, a ceiling, by manipulating PRCONT. PRCSW must be set to 1. CIPERT should also be modulated.
Deferred Interest Payments	Interest payments on debt can be deferred, thus freeing cash for investment; accomplished by changing DINTT.
Environmental Regulations	The impact of environmental regulations can be modified via EEICT and EEOPCT for capital, and EEIPLT and EEOPLT for labor.
Dividends	Divident payments can be rerouted to investment via EFEDT.
Government Debt	Government can inject cash into the economy by means of loans to sectors, using GDBTAT. CIPERT should be adjusted to reflect resultant inflation, if any.
Government Debt Policy	The government can force the commercial lending institutions to lend based on higher debt/equity ratios via GEGLT.
Depreciation	Government can allow faster depreciation, diverting cash into investment. GPDTT must be changed.
Stockpile Protection	The government can protect stockpiles via GPSLT.

FIGURE A-2 (continued)

Stockpile Release	Altering the shape of GSRSDT changes the sensitivity of stockpiles released to supply/demand balance in the economy. GSPOLT also impacts releases. Changing GTGPB can also affect sensitivity by changing the government's perception of the view of the economy for stockpiled goods.
Stockpile Building	Changing GSPP and GSPPT can help answer the question: "What if the government had large stockpiles?"
Stockpile Sales	Government stockpiles are assumed to be sold at market value, potentially straining the ability of producers to buy needed material. Changing GSSPOL to 0 allows release of stockpiles gratis.
Taxation Policy	Changing GTIPT can relieve (or worsen) income taxation.
Mobilization	Mobilization (and its demands on the economy) are simulated by setting MTIME to the mobilization time, and MLENTH to the mobilization length. Then, GIDMT must be set to reflect increases in government demand for resources. The priority of government for obtaining those resources (GDPRN) may also be altered under these conditions.
Rationing	Rationing of natural resources is accomplished by setting the duration of rationing RATLEN to a non-zero number. The start time of rationing is assumed to be one year post attack (RATIME); this too can be altered. The amount of resource to be rationed to each demanding sector is set via RATA, RATB, RATC, RATE, RATG, RATR, RATS, RATT, and RATU.
Balance Sheet	Balance sheets are reduced proportional to destruction unless ZBSBS, ZBSCS, ZBSDS, ZBSES, and ZBSVIS are set equal to 0.
Labor Relocation	Labor can be removed temporarily from the economy via ZSRGLF for a duration of ZSRGT years.

The list of recovery policies in Figure A-2 contains only those policies that are more or less explicitly represented in the model. Other scenarios are easily simulated by inputting to the model the effects of such a scenario. For example, although the model cannot explicitly institute a massive shelter-building program, it can easily simulate the effects of such a program by means of huge increases in demand to the natural resource industries (particularly metallic durable materials, non-metallic durable materials, and energy), and, at attack time, a disproportionately lower loss of labor relative to destruction of capital and inventory.

The user also should realize that the model contains an entire structure of default calculations which simulate destruction in the remainder of the economy based on the key attack inputs to the model. Although a user can easily change all assumptions from the default at any time, this default structure allows simple use of the model without the need to specify dozens of parameters.

Run Streams

The following listings contain the parameter inputs used to simulate the scenarios contained in this document. Each "RUN" card corresponds to one of the simulations explicitly mentioned in Chapter VII of this report.

```
CP SAVPER=.5
TP PRTPR=0/0/0/0/0/0
TP CIPERT=.08/.40/.20/.15/.15/.10/.08
TP ZIMPUN=1/1/5/5
T  ZFC=.1/.1/.1/.1
T  ZFI=.1/.1/.1/.1
T  ZFB=.1/.1/.1/.1
T  ZAPED=.1/.1/.1/.1
CPLOT EPROD.BASE=E,EPROD=*(0,100E9)/MPROD.BASE=M,MPROD=+(0,160E9)
RUN LOW -- LOW DAMAGE
T  ZFC=.1/.1/.1/.1
T  ZFI=.1/.1/.1/.1
T  ZFB=.1/.1/.1/.1
T  ZAPECC=.5/.5/.5/.5
T  ZAPED=.5/.5/.5/.5
T  ZAPELC=.5/.5/.5/.5
T  ZARTC=10/10/10/10
T  ZARTD=10/10/10/10
T  ZARTL=10/10/10/10
C  ZISC=1
C  ZISL=1
CPLOT EPROD.BASE=E,EPROD=*(0,100E9)/MPROD.BASE=M,MPROD=+(0,160E9)
RUN LOWNR -- LOW DAMAGE TO NATURAL RESOURCES
T  ZFC=.1/.1/.5/.1
T  ZFI=.1/.1/.5/.1
T  ZFB=.1/.1/.5/.1
T  ZAPED=.1/.1/.1/.1
CPLOT EPROD.BASE=E,EPROD=*(0,100E9)/MPROD.BASE=M,MPROD=+(0,160E9)
RUN SURCL -- SURGICAL STRIKE
T  ZFC=.05/.05/.5/.05
T  ZFI=.05/.05/.5/.05
T  ZFB=.05/.05/.5/.05
T  ZAPED=.05/.05/.05/.05
CPLOT EPROD.BASE=E,EPROD=*(0,100E9)/MPROD.BASE=M,MPROD=+(0,160E9)
RUN HYPER -- HYPER SURGICAL STRIKE
T  ZFC=.05/.05/.05/.05
T  ZFI=.05/.05/.05/.05
T  ZFB=.05/.05/.05/.05
T  ZAPED=.5/.5/.5/.5
C  ZISL=1
T  ZAPELC=.5/.5/.5/.5
CPLOT EPROD.BASE=E,EPROD=*(0,100E9)/MPROD.BASE=M,MPROD=+(0,160E9)
RUN NEUT -- NEUTRON BOMB ATTACK
T  ZFC=.4/.4/.4/.4
T  ZFI=.4/.4/.4/.4
T  ZFB=.4/.4/.4/.4
T  ZAPED=.4/.4/.4/.4
CPLOT EPROD.BASE=E,EPROD=*(0,100E9)/MPROD.BASE=M,MPROD=+(0,160E9)
RUN HEAVY -- HEAVY DAMAGE
```

```
CP SAVPER=.5
CP PLTPER=.5
TP PRTPR=0/0/0/0/0
TP CIPERT=.08/.40/.20/.15/.15/.10/.08
TP ZAPED=.1/.1/.1/.1
TP ZFB=.1/.1/.5/.1
TP ZFC=.1/.1/.5/.1
TP ZFI=.1/.1/.5/.1
TP ZIMPUN=1/1/5/5
CPLOT EPROD.BASE=E,EPROD=*(0,100E9)/MPROD.BASE=M,MPROD=+(0,160E9)
RUN BASEATT -- BASE ATTACK
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
C  GSW=0
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN RELCUR -- RELEASE CURRENT STOCKS
C  GSW=0
T  GSPP=40E9/0/50E9/0
C  GTGPB=.25
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN RELHYP -- RELEASE HYPOTHETICAL STOCKS
C  GSDPRN=1
T  GSDEST(*,1)=0/40E9/40E9/40E9/40E9/40E9
T  GSDEST(*,3)=0/50E9/50E9/50E9/50E9/50E9
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN BLDSTK -- BUILD TO HYPOTHETICAL STOCKS
T  EEIPCT=1/1/1/1
T  EEOPCT(*,1)=1/1/1/1/1/1/1/1/1
T  EEOPCT(*,2)=1/1/1/1/1/1/1/1/1
T  EEOPCT(*,3)=1/1/1/1/1/1/1/1/1
T  EEOPCT(*,4)=1/1/1/1/1/1/1/1/1
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN NOENVR -- NO ENVIRONMENTAL REGULATIONS
TT CIPERT=.08/.09/.09/.09/.08/.08/.08/.08/.08/.08/.08
C  PRCNLN=5
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN WGPRCN -- WAGE AND PRICE FREEZE
TT CIPERT=.08/.09/.09/.09/.08/.08/.08/.08/.08/.08/.08
C  PRCNLN=5
T  PRCONT=900/70/315/4000
C  PRCSW=1
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN WGPRHP -- WAGE AND PRICE CONTROL
T  GSUBT(*,1)=0/20E9
T  GSUBT(*,2)=0/5E9
T  GSUBT(*,3)=0/100E9
T  GSUBT(*,4)=0/50E9
T  GEGLT=1/2/1.5/1.25/1
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN SUBDE -- GOVERNMENT SUBSIDIES
T  GTIPT(*,1)=1/.6/.9/1
T  GTIPT(*,2)=1/.6/.9/1
T  GTIPT(*,3)=1/.6/.9/1
T  GTIPT(*,4)=1/.6/.9/1
```

```
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN INCTAX -- INCOME TAX RELIEF
T   GSUBT(*,1)=0/20E9
T   GSUBT(*,2)=0/5E9
T   GSUBT(*,3)=0/100E9
T   GSUBT(*,4)=0/50E9
T   GEGLT=1/2/1.5/1.25/1
T   GTIPT(*,1)=1/.6/.9/1
T   GTIPT(*,2)=1/.6/.9/1
T   GTIPT(*,3)=1/.6/.9/1
T   GTIPT(*,4)=1/.6/.9/1
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN COMBO1 -- FINANCIAL COMBO, INCTAX AND SUBDE
C   GSW=0
T   GSPP=40E9/0/50E9/0
C   GTGPB=.25
C   GSSPOL=0
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN GRATIS -- FREE STOCKPILE RELEASES
T   GSUBT(*,1)=0/20E9
T   GSUBT(*,2)=0/5E9
T   GSUBT(*,3)=0/100E9
T   GSUBT(*,4)=0/50E9
T   GEGLT=1/2/1.5/1.25/1
T   GTIPT(*,1)=1/.6/.9/1
T   GTIPT(*,2)=1/.6/.9/1
T   GTIPT(*,3)=1/.6/.9/1
T   GTIPT(*,4)=1/.6/.9/1
TT CIPERT=.08/.09/.09/.09/.08/.08/.08/.08/.08/.08/.08
C   PRCNLN=5
T   PRCONT=900/70/315/4000
C   PRCSW=1
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN COMBO2 -- COMBO1 AND WGPRHP
T   GSUBT(*,1)=0/20E9
T   GSUBT(*,2)=0/5E9
T   GSUBT(*,3)=0/100E9
T   GSUBT(*,4)=0/50E9
T   GEGLT=1/2/1.5/1.25/1
T   GTIPT(*,1)=1/.6/.9/1
T   GTIPT(*,2)=1/.6/.9/1
T   GTIPT(*,3)=1/.6/.9/1
T   GTIPT(*,4)=1/.6/.9/1
TT CIPERT=.08/.09/.09/.09/.08/.08/.08/.08/.08/.08/.08
C   PRCNLN=5
T   PRCONT=900/70/315/4000
C   PRCSW=1
T   EEIPCT=1/1/1/1
T   EEOPCT(*,1)=1/1/1/1/1/1/1/1/1
T   EEOPCT(*,2)=1/1/1/1/1/1/1/1/1
T   EEOPCT(*,3)=1/1/1/1/1/1/1/1/1
T   EEOPCT(*,4)=1/1/1/1/1/1/1/1/1
CPLOT EPROD.BASEATT=E,EPROD=*(0,100E9)/MPROD.BASEATT=M,MPROD=+(0,160E9)
RUN COMBO3 -- COMBO2 AND NOENVR
```

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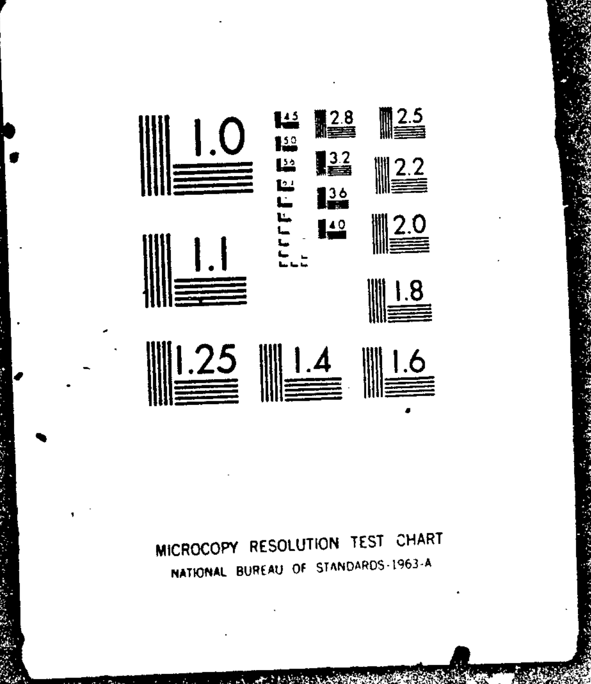

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DEVELOPMENT OF A DYNAMIC MODEL TO EVALUATE THE EFFECT OF NATURAL RESOURCE POLICIES ON RECOVERY FOLLOWING NUCLEAR ATTACK (Unclassified)
Pugh-Roberts Associates, Inc. September 1981
DCPA01-78-C-0302, W.U. 4341B
A dynamic computer simulation model which explicitly represents the production, import, and distribution of key groups of natural resources and the effects of resource-related government policies. The model is a tool for assessing the U.S. economy's vulnerability to damage to its natural resource sectors. It can be used to analyze impacts of resource availability and of U.S. Government natural resource policies on the process of post-nuclear-attack economic recovery. The model may be characterized as a dynamic, input-output simulation of the natural resources portion of the U.S. economy. The natural resources portion of the economy is represented as four distinct sectors: (a) metallic durable materials; (b) non-metallic durable materials; (c) energy products; and (d) non-fuel consumable materials. The results of attack scenario and policy tests indicate that recovery following a nuclear attack requires reestablishing and maintaining dynamic balance among the interdependent sectors of the economy. Under a wide range of attack scenarios, the natural resource sectors will be sources of dangerous imbalances, and will constrain recovery of the overall U.S. economy. Civil Defense policies can reduce these imbalances and thus merit serious consideration. This work is an extension to, and enhancement of, the dynamic modeling effort under Contract No. DCPA 01-78-C-0302.

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